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RESEARCH AND DEVELOPMENT ON THE BASIC DESIGN OF
STORABLE HIGH-ENERGY PROPELLANT SYSTEMS AND COMPONENTS

BELL AEROSYSTEMS COMPANY
Buffalo, N. Y.

Final Report
AFFTC TR-60-61

Contract No. AF33(616)-6689

19 MAY 1961

Commander
AIR FORCE FLIGHT TEST CENTER
EDWARDS AIR FORCE BASE
CALIFORNIA

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FOREWORD

This document is the final report prepared by Bell Aerosystems Company for the Air Force Flight Test Center, Edwards Air Force Base, under Contract AF33(616)-6689. The program is the study of storable, liquid-propellant systems. The period with which this report is concerned is 6 July 1959 through 30 September 1960.

The nomenclature of aluminum alloys which is used in this report is that which has been accepted as standard by the Aluminum Association. That which is used for stainless steel has been established by the American Iron and Steel Institute (AISI).

ABSTRACT

The storable liquid propellants studied under this contract were nitrogen tetroxide (N_2O_4), unsymmetrical dimethylhydrazine (UDMH), and hydrazine (N_2H_4). The prime effort was expended on the first two propellants. Experimental data as well as data obtained from a literature survey are included in this report.

Pertinent physical property data is presented for each propellant. Data concerning propellant decomposition caused by such contaminants as aluminum and stainless steel chips, lint, constituents of air and hot pressurizing gases is also presented. High temperature, low temperature, and cycling temperature tests were conducted with each propellant in tanks made of type 347 stainless steel, 6061-T6 aluminum, PH 15-7 Mo stainless steel and C 120 AV titanium. Three explosions were encountered with N_2H_4 in stainless steel tanks (347 stainless steel and PH 15-7 Mo stainless steel) at temperatures above 290°F. Other than slight decomposition, no problems were encountered with UDMH stored at temperatures up to 300°F. If N_2O_4 is maintained in the anhydrous state and high vapor pressure can be tolerated, no problems will be expected with N_2O_4 stored in type 347 stainless steel, PH 15-7 Mo stainless steel, and 6061-T6 aluminum tanks up to 270°F. Neither tank corrosion nor propellant decomposition was detected when the propellants were stored for three to six months in 10-gallon 6061-T6 aluminum and PH 15-7 Mo stainless steel tanks at outdoor temperatures and temperatures near the propellant boiling points. Materials compatibility data is presented for each of the propellants.

Flow and exposure tests were conducted with Rascal type hardware converted to operate with N_2O_4 and UDMH. Anti-fricition bearings such as ball or roller bearings made from standard SAE 52100 series bearing steel or 440 C stainless steel were satisfactorily run and lubricated in liquid N_2O_4 in a seal test rig. In addition, several seal configurations were evaluated with N_2O_4 and showed excellent wear qualities when run against 316 stainless steel and flame-plated chromium carbide mating rings. Pump tests were conducted with the WS 117L (Bell Agena) pump hardware to determine the pump cavitation characteristics with UDMH and N_2O_4.

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I. INTRODUCTION

This is the final report under Contract No. AF33(616)-6689 conducted by Bell Aerosystems Company under the sponsorship of the Directorate of Rocket Propulsion, Air Force Flight Test Center, Edwards Air Force Base, California. Mr. C. F. Emde was the Project Officer.

This work covers the period 6 July 1959 through 30 September 1960. During the first three months of this period, an extensive literature investigation was conducted to accumulate information pertinent to the test program. The major portion of the effort under this program was utilized in experimentation and testing with storable propellants (N_2O_4, UDMH, and N_2H_4) to resolve such problems as propellant temperature limits, materials compatibility, propellant decomposition, sealing, pumping, and flowing propellants through a typical missile propellant system.

II. DISCUSSION

Phase I, a literature survey, was conducted during the first three months of this contract. Detailed results of this investigation were reported in the first quarterly progress report (Reference 1 in the Bibliography). Highlights of this survey are included in a detailed description of the basic laboratory investigations (Phase II) and system and component analysis (Phase III) which are discussed in the following subsections.

A. PHASE II — BASIC LABORATORY INVESTIGATIONS

1. Propellant Properties

During the first three months of this contract, information and data on the physical properties of N_2O_4, UDMH, and N_2H_4 were compiled from existing literature. Additional information and data were obtained during the succeeding months from continuing literature survey, and tests were undertaken at Bell Aerosystems to bridge gaps in the existing literature.

Tests conducted at Bell Aerosystems during this period were:

(1) The viscosity of N_2O_4 was measured using an Ostwald-Cannon-Fenske viscosimeter in the temperature range from -4.4 to 50°F.

(2) The density of N_2H_4 in the temperature range from 122 to 230°F was measured using a Westphal Balance, a Pyrex test tube, and a temperature controlled oil bath.

(3) The flash and fire points of N_2H_4 were determined using a Cleveland Open Cup Apparatus modified to eliminate catalytic effects by using a glass cup.

(4) The flash and fire points of UDMH were determined by the Cleveland Open Cup and the Pensky-Martens Closed Cup apparatuses.

The propellant physcial properties of primary interest to rocket engine manufacturers are summarized in Table 1. The corresponding references are also noted in this table.

Table 2 and Figure 1 contain density values of N_2O_4 as a function of temperature. Vapor pressure data for N_2O_4 are tabulated in Table 3, and are plotted in Figure 2 as a function of temperature. The viscosity of N_2O_4 in the liquid phase from 40 to 280°F is tabulated in Table 4. The effect of temperature and pressure on viscosity in the liquid phase of nitrogen tetroxide can be found in Figures 3 and 4. The viscosity of N_2O_4 at temperatures below 50°F is tabulated in Table 5. Figure 5 shows a comparison of results obtained at Bell versus those obtained by Richter and Sage for N_2O_4 viscosity. Table 6 and Figure 6 contain heat capacity values of N_2O_4 as a function of temperature. The dissociation of N_2O_4 as a function of temperature and pressure can be seen in Table 7.

Tables and plots of the density, vapor pressure, viscosity, and heat capacity as functions of temperature were prepared for UDMH. Table 8 and Figure 7 illustrate density values, and Table 9 and Figure 8 show vapor pressure data. Viscosity values may be found in Table 10 and Figure 9, and the heat capacity values may be found in Table 11 and Figure 10.

Also, tables and plots of the density, vapor pressure, viscosity, and heat capacity as functions of temperature were prepared for N_2H_4. Tables 12 and 13, along with Figures 11 and 12, illustrate density and specific gravity data. Table 14 and Figure 13 show vapor pressure data. Viscosity values may be found in Table 15 and Figure 14, and the heat capacity data may be found in Table 16 and Figure 15.

Finally, curves of the density versus temperature over the liquid range, for N_2O_4, UDMH, and N_2H_4, along with their melting points and boiling points, were plotted as Figure 16. From these curves, the coefficient of thermal expansion of the three propellants can be obtained.

2.   Propellant Decomposition

Data pertinent to the effect of propellant decomposition, due to contact with air, manufacturing dirt, and pressurizing gases, are given in this section. That found in a literature survey is listed in the succeeding paragraphs.

Slow decomposition was noted in most cases, due to a reaction between oxygen and N_2H_4 at ambient temperature. At higher fuel temperatures, a faster decomposition rate was noted.

UDMH is resistant to air oxidation, but the vapor reacts slowly at ambient temperature to form traces of several products. Carbon dioxide reacts with UDMH to form a salt*, and extended exposure of UDMH to air or other gases containing carbon dioxide could lead to eventual precipitation of the material (Reference 12). W. A. Riehl (Reference 20) bubbled a volume of air equal to 12,000 times the original liquid volume of UDMH and found the quality of the UDMH had changed drastically. The UDMH had turned orange-red, the concentration dropped from 97.8 to 39.3%, and the specific gravity increased from 0.795 to 0.989.

Although pressurized nitrogen is used for transferring UDMH and N_2H_4 (References 3, 6, and 12), and dry compressed air for transferring N_2O_4 (Reference 9), very little experimental data was found concerning the effects of propellant decomposition caused by hot pressurized nitrogen gas. Rocketdyne (Reference 22) advised caution when pressurizing hot (200 F) N_2H_4 with hot nitrogen (1000 F) becuase explosions have been experienced under similar conditions. Carbon dioxide was found to be unsatisfactory as a pressurizing gas for N_2O_4 because of its solubility in the oxidizer (Reference 18).

A. G. Thatcher of Reaction Motors Division (Reference 19) reported smooth runs when expelling N_2H_4 at ambient temperature (70 F) and at 200 F with OGK solid-grain gas products** cooled by a diluent. No vapor phase N_2H_4 detonation was detected, presumably because of the rapid dilution of the N_2H_4 vapor with grain gases.

In general, the personnel at each facility visited advised caution when expelling hot N_2H_4 with hot nitrogen.

Rocketdyne, Jet Propulsion Laboratory, and Aerojet-General predict no problem when pressurizing N_2O_4 and UDMH with hot nitrogen. Allied Chemical Corporation (Reference 32) indicates no problem will be encountered when pressurizing N_2O_4 with hot nitrogen. Westvaco Chlor-Alkali Division of FMC (Reference 33) recommends caution when pressurizing UDMH with nitrogen at $1000°F$ because the decomposition temperature of UDMH is $1200-1400°F$.

* $(CH_3)_2 N_2HCOOH$

** $(H_2, CO, CO_2, H_2O, N_2, NH_3)$

Manufacturing dirt refers to matter such as stainless steel and aluminum chips, weld scale, lint, greases, shreds of plastic material, and lubricants which may be found in a missile propellant system. As originally interpreted, manufacturing dirt was thought to refer to contaminants found in the propellants as received from the vendors. Accordingly, this information was sought from the propellant vendors.

Nitrosyl chloride and water were indicated by the vendor (References 9 and 32) to be the most likely contaminants in N_2O_4. Water, when combined with N_2O_4, forms 60-70% solution of HNO_3. Other contaminants might be iron, in the order of parts per million; Nordcoseal 234S (lubricant used by vendor) resulting from excessive use; and the compression oil resulting from the use of dry compressed air during N_2O_4 transfer operations.

Dimethylamine, water, and an air oxidation product, methylene dimethylhydrazine, were indicated by one vendor to be the most likely contaminants of UDMH (Reference 33).

Aniline, chlorides, metal ions, and water were reported to be the most likely contaminants of N_2H_4 (Reference 42).

As this interpretation of manufacturing dirt was not the intended one, most of these propellant contaminants were not included as part of the basic laboratory tests. However, the foregoing data has been included for information purposes.

The following paragraphs give details of tests which were undertaken to supplement the data accumulated in the above paragraphs and round out the data on propellant decomposition.

A series of tests were conducted which involved bubbling O_2, CO_2, and CO through the propellants at a constant flow rate at ambient temperature and temperatures near the propellant boiling points, to determine the effects of contact with air on propellant decomposition. Since the information obtained in the literature survey previously described indicated that CO_2 reacts with UDMH and is soluble in N_2O_4, CO_2 tests with these propellants were not carried out. As no reaction between N_2O_4 and oxygen was likely, this test also was not made. Table 17 shows the results of the tests actually conducted.

These results indicate that CO does not decompose UDMH, N_2H_4, or N_2O_4 at ambient or at temperatures near the propellant boiling points. Tests conducted at ambient temperature, by bubbling O_2 through UDMH and N_2H_4, definitely indicated decomposition so further tests at higher temperatures were not considered necessary. Tests with N_2H_4 and CO_2 were terminated shortly after starting because of the formation of a heavy white precipitate of carbazic acid ($N H_2N HCOOH$) (Reference 4). In view of the rapidity of this reaction at room temperature, no further tests of CO_2 and N_2H_4 were deemed necessary.

Another series of tests were conducted to determine the effects of manufacturing dirt on propellant decomposition.

In the first test, three different amounts of three contaminants were added to eight ounce ground glass stoppered flasks containing approximately three ounces of UDMH. The contaminants were type 6061-T6 aluminum chips, type 347 stainless steel chips, and lint. Test duration was 24 days at ambient temperature. As can be seen in Table 18, analysis obtained on the 17th day, and at the end of test, indicate that no decomposition occurred.

A second series of tests with UDMH was conducted at 160°F. In this case, only the highest concentration of the three contaminants was added to eight ounce flasks fitted with reflux condensers and placed in a constant temperature bath.

This test proceeded for a period of seven days at 160°F. Analytical results obtained before and after test can be seen in Table 19. These results indicate that the contaminants tested have no effect on the UDMH at elevated temperatures.

The next series of tests conducted was the same as the first series except that hydrazine was used in place of UDMH. Analytical results and concentrations used are shown in Table 18. These results also indicate that these contaminants have no effect on the N_2H_4 at ambient temperature.

The fourth series of tests conducted was the same as the second series except that N_2H_4 was used in place of UDMH. Analytical results as shown in Table 19 give no evidence of propellant decomposition at 160°F.

The fifth and sixth series of tests were conducted with N_2O_4, first at temperatures approximately 40°F and then at 70°F. The flasks used were similar to those mentioned in the above tests but in place of condensers, vapors were retained in the elevated temperature tests by enclosing the flasks in a container made of aluminum and holding flask stoppers down by compressing the lid of the box. The container had port holes so that visual observations could be made from time to time. Tables 20 and 21 show the test details and results. No propellant decomposition was apparent.

3.   Purging and Pressurization

The tests for determining the effects of high temperature nitrogen on liquid propellant decomposition were conducted using the test apparatus as shown in Figure 17. Preliminary tests using water as the expelled liquid were conducted to calibrate the equipment and to provide data as a reference for indications of reactions. A time history curve of representative data accumulated during these tests is shown in Figure 18. Test conditions prior to the expulsion of the water included preheating the nitrogen in the nitrogen tank to approximately 1000 F. The water was preheated in a separate bath to approximately 200 F. Reference to the schematic (Figure 17) will show the approximate locations of this equipment. The temperature of the pressurizing gas is controlled by an electrically heated sand bath. A similar arrangement, although not shown on the schematic, was employed to control the liquid bulk temperature. The nitrogen tank was pressurized prior to heating to a predetermined value P_1 by the equation: $P_1 \quad \dfrac{T_1 P_2}{T_2}$.

When the nitrogen temperature and pressure, and the liquid temperature were stabilized to run condition, the recorders were turned on the nitrogen pressure was increased by increasing the system pressure with the Grove loader (A) until the shear disc (B) ruptured at approximately 1050 psig. Pressure switch (C), located in the propellant discharge line, initiated propellant flow at a tank pressure of 1000 psig. Thermocouples and pressure transducers were located as shown in Figure 17.

T_1 = measures inlet gas temperature of propellant tank

T_2 = measures gas temperature of ullage of propellant tank

T_3 = measures liquid temperature in the propellant tank

T_4 = pressurizing gas tank temperature

P_1 = upstream of check valve

P_2 = downstream of check valve

P_3 = pressurizing gas tank pressure (top)

P_4 = propellant tank gas pressure (top)

P_5 = propellant tank liquid pressure (bottom)

a. N_2O_4 Tests

System preparation prior to tests with N_2O_4 included a pickling process with a solution of nitric acid, hydrofluoric acid, and water at $140°F$. Approximately 1.5 quarts of N_2O_4 were loaded in a two-quart 347 stainless steel propellant tank. The N_2O_4 tests were conducted at an ambient temperature of approximately $70°F$. The nitrogen temperature was increased to $1120°F$. With reference to Figure 19, T_1 (propellant tank inlet temperature) is initailly affected by the vapor temperature of the liquid. This temperature shows an increase during the course of the run to a temperature of $475°F$. The temperature in the ullage space, however, increased at a relatively slow rate until at propellant exhaustion the maximum temperature increased to $190°F$.

b. UDMH Tests

System preparation prior to tests with UDMH included a system flush procedure with methylene chloride, methanol, methylene chloride, and hot ($160°F$) N_2 purge. The system was then loaded with a 20%-by-weight solution of N_2H_4 and heated to $160 F$ for a two hour period. Results of these tests with UDMH are shown in Figure 20. It will be noted that although the UDMH was preheated to $140°F$, the temperature traces are similar to the N_2O_4 tests.

c. N_2H_4 Tests

Additional system preparation, other than an N_2H_4 flush, was not considered necessary following the UDMH tests. N_2H_4 tests were conducted at two propellant temperatures, 170 and $223°F$ (Figures 21 and 22). The temperature traces for each run compare with those of N_2O_4 and UDMH. An additional run was attempted to substantiate this finding at $225°F$. During pre-run temperature conditioning, with the propellant temperature at $143°F$ and an ullage temperature (T_2) of $290°F$, a tank rupture occurred. The design burst pressure of the tank used was 2500 psig. No apparent reason is known for this sudden violent reaction since this system was used for UDMH and N_2H_4 on the preceding tests.

It is recommended that additional tests be conducted to substantiate these findings with larger quantities of propellants, increased surface-to-volume relationship, higher temperatures, and at various pressurizing rates.

Based on the experiences of other activities and those at Bell Aerosystems Company, it is apparent that by pressurizing both N_2O_4 and UDMH within the temperature range covered by these tests, no propellant decomposition is expected. To determine the safe operating limitations with N_2H_4, more tests should be conducted as mentioned above.

4. Temperature Limits

Complete information concerning the effect of temperature, time, and container material on propellant storage properties was not found during the literature survey. The information, which was found, concerning different phases of this work, follows.

Arthur J. Grant, Jr. (Reference 55) reported, at an ARDC Industrial Symposium, that some N_2H_4 decomposition occurs at all normal temperatures and that the rate of decomposition depends on the material with which it is in contact. With most 18-8 stainless steels, and aluminum, the rate of decomposition is negligible up to a temperature as high as $300 F$. At $160 F$, decomposition is barely detectable. At $500 F$, explosive conditions are reached.

Shock sensitivity tests with UDMH and N_2H_4 have been determined using a modified Bureau of Mines standard card gap test. These tests were made at approximately 18°F below boiling points and the results indicate that both UDMH and N_2H_4 were relatively insensitive (Reference 15 and Table 22).

Table 23, compiled originally by A. G. Thatcher (Reference 19), summarized some of the recent results from a laboratory bomb type detonation test program for N_2H_4 and UDMH blends. The results indicate the marked detonation suppression qualities of reasonably small additions of UDMH. Details of these tests were not described in the report.

Aerojet-General Corporation has conducted vapor phase thermal stability tests of N_2H_4 and N_2H_4 mixtures. A laboratory apparatus, made of types 347 and 17-7 PH stainless steel and designed to determine the relative thermal stability of vaporized fuels, was used. The rate of pressure increase during decomposition induced by thermal shock from a tantalum wire was measured as the indication of relative thermal stability. UDMH and ammonia, as additives, reduced the rate of vapor phase thermal decomposition of the N_2H_4. (Reference 56).

The catalytic activities of metal surfaces (Reference 57) were studied by inserting strips of metal into pyrex ampoules before filling with N_2H_4, and raising the combination to temperatures above the boiling point of N_2H_4. In general, this caused a large increase in rate of decomposition over that obtained in pyrex alone. Type A nickel, aluminum, and stainless steel 302 were studied, and the least active of the untreated (unpassivated) specimens was aluminum. At the temperature at which the runs were made, the resulting decomposition was attributed almost completely to the presence of the metal.

According to Aerojet-General (Reference 21), NOTS Report NAVORD 6469 contains curves of pressure versus time for the three propellants under consideration at 300 and 250 F. These curves indicate that UDMH and N_2O_4 would present no problem at 300 F. N_2H_4 would decompose with time. However, the time mentioned in this report was relatively short in comparison to the three-month period required in this program.

Since the information referenced above did not give all the data required, the following series of tests were conducted.

The first tests in this series were conducted with small airborne type tanks of types 347 and PH 15-7 Mo stainless steel, 6061-T6 aluminum, and C 120 AV titanium, to determine the effect of high temperature (300±10 F for UDMH and N_2H_4, and 270±10 F for N_2O_4), time, and material on the stability of the three propellants.

The second set of tests in the series was designed to determine the effect of low temperature (-65±10 F for UDMH and N_2H_4, and -20±10 F for N_2O_4), time, and material on the stability of the three propellants.

The third set of tests in the series was designed to give a combination of the other two. This test involved cycling from -40 to 300 F for UDMH, -20 to 300 F for N_2H_4, and -20 to 270 F for N_2O_4 using the same ullage and tanks specified for the first tests.

a.   Elevated Temperature Tests

The first tests with UDMH and N_2H_4 at 300±10 F were run with type 347 stainless steel and 6061-T6 aluminum tanks. Tanks of PH 15-7 Mo stainless steel and titanium had not been received from the vendor, at this point, and could not be included in these early tests. Tank size, material of construction, propellant loaded, and ullage used are given in Table 24. (The term "ullage"

in this report means the vapor space above the liquid.) The tanks were hydrostatically tested according to a standard military specification (Reference 88). The stainless steel tanks were pickled with a nitric acid/hydrofluoric acid/water mixture (Reference 60), and the aluminum tanks were pickled with a sodium dichromate/sulfuric acid solution (Reference 61). These tanks were mounted on a cross bracket and placed in an oven as shown in Figures 23 and 24. Note, in Figure 24, that the four tanks mounted on the back side of the cross bar were loaded with N_2H_4 and designated 1 through 4 from left to right, and the four tanks mounted on the front side of the cross bar were loaded with UDMH and are designated 5 through 8 from left to right. Each of the tanks was equipped with a visual pressure gauge, vent valve, temperature probe, and a 600-psi designed burst pressure shear disc. These discs were connected via a common discharge line to a water pot located outside of the cell used. Tanks were then filled with propellants at ambient temperature to the ullage designated in Table 24. The ullages used were selected on the basis of the thermal expansion of each propellant, and to compare data for two different ullages. The sealed system was examined for leaks before and after loading propellants. After the system was found to be free from leaks, the test was started. Pressure rise-rate, for the first five-hour heating to the desired temperature, for the N_2H_4, averaged 15 psig/hour, and for the UDMH, approximately 11 psig/hour. After the temperature stabilized at 300 ±10 F, tanks 2, 3, and 4, containing N_2H_4, continued to show a pressure rise-rate of approximately 26 psig/hour while tank 1 tapered off to approximately 1 psig/hour (Figure 25). Tanks 5 through 8, containing UDMH, after the first five hours tapered off to approximately 0.7 psig/hour (Figure 26). The pressure rises in the N_2H_4 tanks indicated that the burst pressure of the shear discs on tanks 2, 3, and 4 would be reached in approximately 23 and 24 hours. The rate of pressure rise of tank 1, indicated that the burst pressure would not be reached for a considerable length of time. This indication was also true for tanks 5 through 8, containing UDMH. After 16 hours of continued heating at 290 F, an explosion occurred demolishing the oven and part of the building (Figures 27 and 28). Subsequent investigation pointed to decomposition of N_2H_4 in stainless steel tank 2 which shattered, sending shrapnel at the other seven tanks, causing tanks 1 and 4 to rupture. Damage to the tanks is shown in Figures 29 and 30. The pressure rise was beyond the normal vapor pressure of N_2H_4 at 290 F. This indicated that catalytic decomposition was occurring. However, the rate was constant, giving no indication of a possible explosion. Later, tank 3 was cut open and found to contain brown iron oxide deposits on the weld surfaces. From this it was judged that the explosion was probably caused by the catalytic decomposition of the N_2H_4 due to these deposits. This conclusion was substantiated during two attempts which were made subsequently to duplicate conditions which caused the explosion.

In the first repeat test, a stainless steel type 347 tank was processed as in the orginal test and loaded with N_2H_4 at the same ullage as tank 2. A visual inspection of the inside surface of the tank, prior to loading, indicated a small amount of brownish residue on the weld surface. This residue was not removed, in order that the test condition would be the same as for the original test. The tank was immersed in a sand bath, contained in a mild steel drum which was located outdoors (Figure 31). This minimized the possibility of damage due to an explosion. The bath was heated with Calrod immersion heaters and the temperature was thermostatically controlled. During the 24 hours of the first repeat test, the maximum pressure obtained was 141 psig; however, this was due to inadvertent attainment of a temperature of 377 F. The average pressure and temperature, excluding the 141 psig at 377 F, was 108 psig at 305 F (Figure 32). The second repeat test was made with the same equipment but fresh propellant. Test duration was approximately 50 hours with shutdowns at the end of the second shift (approximately 12-14 hours at temperature). The maximum pressure was 91 psig (Figure 33).

These tests indicate that the tank became conditioned because it was exposed to 300°F, and above, with concentrated N_2H_4, resulting in only a gradual rise in pressure as compared to the original test. These tests also indicate that the decomposition rate of N_2H_4 is such that long term tests at constant temperature in tanks which have been properly cleaned and conditioned seem permissible. Analysis of the N_2H_4, before and after test, showed only slight decomposition (97.57% at the start and 97.14% after test).

It was then decided to conduct separate tests using the above mentioned system with PH 15-7 Mo stainless steel, 6061-T6 aluminum, and C 120 AV titanium alloy tanks. These tanks were conditioned and tested for a 24-hour period.

At this point, further temperature limits testing was transferred to an area where better provisions could be made to cope with potential hazards involved.

During the time required to set up operations at the new site, the two-quart PH 15-7 Mo stainless steel and C 120 AV titanium tanks arrived from Benson Manufacturing Company. Using these tanks and two-quart 6061-T6 aluminum and type 347 stainless steel tanks, three series of tests were started with UDMH and N_2O_4.

In each case, operations commenced with determining tank volume by calibration with water. This was followed by pickling in accordance with Reference 61. As an added precaution, tanks intended for fuel tests were filled with dilute (35% by volume) UDMH and held at 190 ± 0°F for one hour, after which they were drained, blown dry with nitrogen, and capped. After the propellant to be used for a given series of tests was analyzed, the tanks were loaded with enough liquid to give a predetermined ullage at loading temperature. Loading was accomplished by the following procedures.

The fuel tanks were evacuated, then filled with nitrogen to provide an inert atmosphere. The UDMH drum was pressurized to force fuel into a graduated dropping funnel via stainless steel and Tygon tubing. The correct volume of fuel was then allowed to flow into each tank, displacing nitrogen during the process.

The oxidizer tanks were fitted with a fill line connected to an N_2O_4 cylinder, and a vent line to carry away NO_2 fumes. The assembly was put on a scale and the cylinder valve opened. Due to the low ambient temperature, the liquid, driven by its own vapor pressure, flowed from one tank to the other.

Each tank was then mounted in an appropriate bath and after burst discs, thermocouples, and pressure gages were satisfactorily installed, temperature control was started. Thereafter, pressure and temperature readings were taken at regular intervals. Detailed information about each series of tests follows.

Three elevated temperature (300 ± 10 F) tests were performed with N_2H_4 in 6061-T6 aluminum, C 120 AV titanium, and PH 15-7 Mo stainless steel tanks, loaded to a 40% ullage after conditioning, and placed in a command sand bath. Within three hours after the start of heating to 300°F, an explosion occurred shattering the PH 15-7 Mo tank and slightly damaging the other two. One minute prior to the explosion, a pressure of 50 psig and a temperature of 298°F were recorded for the PH 15-7 Mo tank, see Table 25. The damage was confined to the test apparatus which was set up outdoors behind a bunker, see Figure 34. Examination of the tank fragment disclosed no evidence of corrosive attack. Fragments of shattered tank are shown in Figure 35. These observations indicate that the explosion was caused by spontaneous catalytic decomposition. As a direct result of this explosion, further N_2H_4 tests at 300°F were confined to 6061-T6 aluminum and C 120 AV titanium.

The remaining two tanks (6061-T6 aluminum and C 120 AV titanium), after being rechecked hydrostatically, cleaned, and conditioned, were placed back in test. These tanks were loaded to 40% ullage with N_2H_4 and held at 300 F for a period of 24 hours. Decomposition was noted for both tanks as indicated by pressure versus temperature curves (Figures 36 and 37). Chemical

analysis, as shown in Table 26, confirms this. This test showed that the order of preference of tank material tested at high temperature (300° F) with N_2H_4 is as follows:

(1) 6061-T6 Aluminum   (3) Type 347 Stainless Steel

(2) C 120 AV Titanium   (4) Type PH 15-7 Mo Stainless Steel

Eight elevated temperature (300 ± 10° F) tests, with UDMH, were conducted for a three-month period. These involved one tank of each material previously mentioned filled to an ullage of 25%, and another to an ullage of 45%. Figure 38 shows the tanks installed in an oven. Figure 39 shows the pressure gages mounted on a wall outside the building housing the oven. The burst disc assemblies are just visible above the gage panel. A cross section of the temperature and pressure data gathered is given in Table 27.

As can be seen by inspection of this table, the tests were interrupted on the fifth day because of leaks at the Teflon vapor seals. Subsequently, oversized Teflon seals were installed and the tests proceeded without incident to the twentieth day when leaks again were detected. At this point, it was decided to switch to butyl rubber seals. During this installation change, the propellant was analyzed and judged acceptable for continuation of the tests. Analytical results before test, and at that point, are given in Table 28. By the 32nd day, the new seals were installed and high-temperature testing resumed.

No further leakage was detected throughout the test period. The test was shut down, however, from the 64th to the 72nd day, to allow disassembly of UDMH cycle (-40 to 300° F) tests which were complete at this point. The elevated temperature test was again interrupted from the 88th to the 89th day, so that a cold box could be installed in the cell for low temperature (-65° F) tests.

Other than the unexpected difficulty of sealing UDMH tanks at elevated temperatures, no basic problems were encountered. Pressure readings up to the 75th day of test were consistently equal to or lower than the vapor pressure of the UDMH, indicating no decomposition. However, after the 75th day, a slight increase in vapor pressure was noted in both of the PH 15-7 Mo stainless steel tanks, indicating some decomposition. Analysis at the end of test (Table 29) confirmed this. The initial and 10% boiling point ranges, as well as density, were below minimum specification. Food Machinery and Chemical Corporation consultants indicated that this was caused by the decomposition products, dimethylamine and ammonia. In the remaining six tanks, which were made of 6061-T6 aluminum, C 120 AV titanium, and type 347 stainless steel, analysis of the UDMH disclosed no decomposition in the aluminum and titanium tanks, and only a slight amount in the type 347 stainless steel tank.

Under the conditions tested, UDMH proved stable in 6061-T6 aluminum and in C 120 AV titanium, and fairly stable in types 347 and PH 15-7 Mo stainless steel.

Four elevated temperature (270 ± 10° F) tests with N_2O_4 were begun on 1 February 1960. One tank of each material specified above was filled to an ullage of 30% mounted in an oven. The ovens and associated lines, gages, and valves, are shown in Figure 40 i   a building in an attitude such that temperature and pressure readings can be made from o   de. A cross section of the data obtained is shown in Table 30.

Inspection of this table shows a lack of data for the titanium tank. Thi: because the tank was removed from test before test conditions stabilized. Removal, in turn, was t   fact that shortly after the propellant reached temperature, NO_2 fumes were seen and subsequently traced to the titanium tank. The propellant was removed and submitted for analysis. The tank was

examined visually and showed no corrosion products. Two pin-hole leaks were discovered at the welds, however, when the tank was hydrostatically tested. The tank was returned to the vendor for repair. Analysis of the propellant at this point and at the beginning of test, as shown in Table 31, indicated no appreciable change in composition during test. While waiting for repairs, information was found in the literature (References 62, 63, and 64), which mitigated against restart of this particular test. It was reported that titanium tends to react with oxidizers, such as RFNA and fluorine, to form deposits which decompose with great violence under slight provocation. Consequently, only the test with the N_2O_4 stored in the titanium tank at a temperature ranging from 90 to 150°F was conducted, and this with provision to detonate any unstable deposits by remote control. This test will be discussed later in this section.

Taken as a whole, test data with the remaining tanks indicate that all of them are satisfactory for high-temperature storage of N_2O_4. Pressures observed were consistent with N_2O_4 vapor pressure data and were proportional to temperature.

The analysis of the N_2O_4, as shown in Table 31, was unchanged except for a trace of nitric acid, found by spectral means, and an indication of the entry of water. Visual examination disclosed salt deposits and indicated definite attack. Salts, which were found in the types 347 and PH 15-7 Mo stainless steel tanks, consisted primarily of hydrated iron nitrate, and in the 6061-T6 aluminum tank, consisted primarily of hydrated aluminum nitrate with a trace of hydrated iron nitrate. The hydrated iron nitrate in the aluminum tank probably came primarily from the stainless steel thermocouple probes used. The observations and analysis seem to indicate that at 270°F, some of the water which had been in the system, or was picked up during the test, reacted with N_2O_4 to form HNO_3. This in turn reacted with the iron and aluminum to form iron and aluminum nitrate which absorbed water to form the hydrates of both nitrates. Consequently when the N_2O_4 was analyzed there was little increase in water content. The salts formed were evidently insoluble in N_2O_4, thereby showing no increase in total solids when an analysis was made.

b. Low Temperature Tests

Eight low temperature (-65 F) tests, four with UDMH and four with N_2H_4, completed one-month storage. One tank of each material (types 347 and PH 15-7 Mo stainless steel, 6061-T6 aluminum, and C 120 AV titanium) was loaded to an ullage of 25% with UDMH, and to 20% with N_2H_4. The tanks were mounted in an insulated box which was cooled by means of a refrigerant. No pressures were recorded throughout the test period, Table 32, and analytical results, as shown in Table 33, indicate no decomposition occurred. Visual inspection of the interior of each tank disclosed no evidence of attack. Accordingly, no preference can be stated for one tank material over another at low temperatures.

Three low temperature (-20 F) tests with N_2O_4 were conducted over a one-month period. These tests involved only the 347, PH 15-7 Mo stainless steel, and 6061-T6 aluminum tanks. No pressures were observed during the test period, and analytical results, as shown in Table 34, as well as visual inspection of the interior of the tanks, indicated no decomposition or attack.

c. Temperature Cycle Tests

Six temperature cycling (-80 to 300°F) tests with N_2H_4 were completed with six weeks storage. These involved two tanks each of three materials, 347 stainless steel, 6061-T6 aluminum, and C 120 AV titanium. One tank of each set filled to 20% and the other to 40% ullage. The tanks were mounted with fittings equivalent to those used for the UDMH temperature cycling tests, and temperature cycling was effected in much the same manner.

Decomposition pressures observed during the test period reached as high as 50 psia. It is assumed that the decomposition was relatively low because of the nature of the test. Where temperature was kept at 300°F for long period of time, much higher pressures were experienced.

A cross section of the temperature and pressure data for the entire test period is given in Table 35. Analytical results, as seen in Table 36, substantiate the claim that only a small mount of decomposition occurred. Further confirmation was obtained upon visual examination of the interior of each tank which showed no signs of corrosion.

Under these test conditions, no preference can be made for any of the container materials tested.

Eight temperature cycling (-40 to 300 F) tests with UDMH were terminated after two months. These too, involved one tank of each material (PH 15-7 Mo, 347 stainless steel, 6061-T6 aluminum, and C 120 AV titanium) filled to 25% and another to 45% ullage. Tanks were mounted, with fittings equivalent to those used at 300°F, in an insulated box and temperature cycling was effected as follows.

Heaters in a second box are turned on and hot air is passed into the box containing the tanks until the temperature reaches 300 F. This takes approximately eight hours. The heaters are then turned off and the propellant cools to ambient temperature in about 12 hours. Dry ice is added to the second box and cold air is passed over the tanks until the propellant reaches -40°F. This also takes about eight hours. The cold air flow is then stopped, and the propellant allowed to rise to room temperature. This takes about 12 hours and completes one cycle. A cross section of the temperature and pressure data for the entire test period is given in Table 37. As with the 300°F test, the sequence was interrupted on the 5th and 20th day for seal replacement. Analytical results, as shown in Table 38, justified continuation of the tests.

No decomposition pressures were observed during the test period. Analytical results at the end of the test (Table 39) disclosed only minor deviations from specification. Visual examination of the interior of each tank showed no corrosion. Under conditions of test, the UDMH was stable in all materials used.

Three temperature cycling (-20 to 270 F) tests with N2O4 were completed with six weeks storage. They involved one tank each of three materials, PH 15-7 Mo stainless steel, 347 stainless steel and 6061-T6 aluminum, filled to an ullage of 30%. The tanks were mounted in an insulated box which was cooled by means of a refrigerant, and heated using resistance heaters.

Pressures, recorded for the three tanks, were equal to, or less than, vapor pressures until the last day of test. On the last day of test, with the temperature at -36 F, a pressure of 30 psig was noted for the 347 stainless steel tank. It was suspected that moisture laden air seeped in via a Teflon "O" ring, which probably developed a slow leak from cold flowing during the cycling and allowed corrosion to set in. This was confirmed when iron nitrate salts were found in this tank, while the remaining tanks, when examined internally, showed no signs of corrosion. A cross section of the temperatures and pressures recorded throughout the tests can be seen in Table 40.

As in the elevated temperature tests, the salts which were formed were quite insoluble in the N2O4. Thus, there was shown no increase in dissolved solids. Complete analytical data gathered for the N2O4 samples are shown in Table 41.

Under the condition of tests, it can be concluded that the N_2O_4 is stable in all three alloy materials, provided no excessive moisture enters the system.

d.   Supplementary Tests

Additional temperature limits tests were made at temperatures above 300° F. Detailed information about each follows.

In each case, propellant was loaded, to an ullage of approximately 90%, into a tank which had been previously cleaned and conditioned. Temperature and pressure pick-ups were added. Next, the tank was mounted in a bath (Figure 41), which was later filled with sand. Pressures and temperatures were recorded. Each tank was also provided with a burst disc rated slightly below its working pressure. This was done so that tanks could be salvaged if pressure rise was not destructive. The tank material selected was considered, from previous tests, to be the most inert in reference to the particular propellant being tested. An N_2H_4 test in 6061-T4 aluminum was terminated after the temperature leveled off at 380 F. A higher temperature was intended but the heating system proved inadequate for this. The test was not repeated, however, since the maximum pressure recorded (480 psig) was considerably higher than the vapor pressure (380 F), indicating propellant decomposition. Figure 42 shows that the rate of decomposition increased sharply above 300° F, and indicates that the pressure would have continued to rise due to propellant decomposition.

A UDMH test in 347 stainless steel rose to a maximum temperature of 567° F and a pressure of 804 psig. Two minutes later, the 1500-pound burst disc ruptured. (See Figure 43.) Vapor pressure data at the corresponding temperature show pressure in excess of 1580 pounds. No UDMH remained in the tank after test, to allow for analysis.

An N_2O_4 test in PH 15-7 Mo stainless steel was terminated after leakage was apparent at a temperature of 406 F. The maximum pressure recorded was 1290 psig. (See Figure 44.) The burst disc was still intact, and it was later found to be the cause of leakage. Analysis of the N_2O_4, indicated no change in composition had occurred.

e.   Miscellaneous Tests

In order to determine if N_2O_4 would form shock sensitive salts when stored in titanium, a C 120 AV titanium alloy tank was loaded with oxidizer to a 50% ullage and mounted in a bath similar to the one shown in Figure 41. The tank, in this case, had a harness shaped fixture mounted on top of it to prevent physical damage to the tank, while at the same time, allowing the tank to absorb the shock of a 50-pound weight dropped from a height of two feet. This was to be done after test, to determine the shock sensitivity of any deposits formed inside the tank during test. Temperature and pressure were monitored throughout the one-month test period (Table 42). Temperature fluctuated between 90 and 150 F, and pressures were consistent with the vapor pressure of N_2O_4 at the prevailing temperatures. The aforementioned weight was dropped on schedule without incident. Analysis of N_2O_4, after test (Table 43), showed no deviation from specification, and examination of the interior of the tank showed no signs of attack or deposit formation. However, a positive result, at a higher impact, was observed in metal coupon tests, as reported in the Materials Compatibility section of this report.

5.   Materials Compatibility

In order to accomplish this program with maximum efficiency and economy, an extensive literature search was first made to determine the areas in which materials data was lacking or sketchy. Following the literature survey, a test program was carried out.

a.   Literature Survey

Tables 44, 45, and 46 are tabulations of literature data on the compatibility of various metals, plastics, elastomers, and lubricants with N_2O_4. Tables 47, 48, and 49 are similar tabulations for UDMH, and Tables 50, 51, and 52 for N_2H_4.

The following general comments, pertinent to this subject, were also obtained from the literature survey.

(1)   Nitrogen Tetroxide (N_2O_4)

Generally, N_2O_4 - NO (nitric oxide) mixtures and N_2O_4 when dry (0.1% moisture, maximum), are not corrosive to mild steel, and numerous other metals, at ordinary tempeatures and pressures. Wet N_2O_4 is as corrosive as 60% nitric acid, so that only materials resistant to 60% nitric acid can be considered useful in wet N_2O_4.

Where metals have been so tested, there is no significant difference in the corrosion of the plain metal versus stressed versus welded specimens. The metals that have been tested in the three different conditions include 8630 steel, 304 stainless steel, and 2024 and 5052 aluminum (References 23 and 25).

Nitrogen tetroxide is very reactive with most organic compounds; therefore, the number of non-metallic materials with which it is compatible is extremely limited (References 25, 26, and 27).

In the case of halogenated plastics, such as Kel F and Teflon, tests indicate that N_2O_4 is absorbed. It is theorized that N_2O_4 is absorbed into the spaces between the polymer chains, forcing apart the chains with resulting swelling and loss of strength (References 26 and 27). Because of this, these plastics should not be used in N_2O_4 and then used in fuel.

As with plastics and elastomers, there is a very limited number of lubricants and sealants that are satisfactory for N_2O_4 service. Becuase of the reactivity of N_2O_4 with organic compounds, hydrocarbon oils and lubricants cannot be used.

One material, generally reported as satisfactory as a sealant and lubricant, is a mixture of graphite with disodium silicate (water glass) or sodium stearate (References 9, 23, 28, 29, and 65).

(2)   Unsymmetrical Dimethyl Hydrazine (UDMH)

A considerable amount of work has been done on the compatiblity of UDMH with both metallic and nonmetallic compounds. However, many details of these numerous tests were not readily available, e.g., such details as the effects of the material on the UDMH, and the initial concentration of the UDMH used in the tests, were not given.

It should be noted that UDMH is generally more stable than N_2H_4, and is compatible with many more metals. Trace quantities of impurities are less likely to catalyze its decomposition, and its reactions with materials are much less violent than in the case of N_2H_4.

In most cases, the presence of moisture adversely affects the corrosion resistance of metals. Figure 45 is a plot showing corrosion rate of several metals versus the UDMH concentration.

(3)   Hydrazine (N2H4)

There have been several compilations of data on N_2H_4 compatibility with various materials of construction. A number of these are listed as references. Most of these articles, however, fail to give all the details of the test conditions regarding the compatibility of the material with the hydrazine. For example, in many instances (Table 50), the data on the effect of the material on N_2H_4 was not available.

In general, high copper and nickel bearing alloys, as well as magnesium, cadmium, bronze, brass, mild steel, lead, tin, and zinc, should be avoided. Regarding molybdenum, Jet Propulsion Laboratory has found polished molybdenum satisfactory when exposed to N_2H_4 up to 400° F in 347 stainless steel bombs (Reference 66).

In view of the limited amount of information concerning the compatibility of N_2H_4 with alloys containing molybdenum, it is recommended that prior to using a molybdenum bearing alloy an evaluation be made employing the conditions expected to be encountered (Reference 70). Most recently at a meeting held at AFBMD, molybdenum bearing alloys were judged satisfactorily for use with a 50/50% (by weight) blend of UDMH-N_2H_4 up to 160 F (Reference 71).

Of the many plastics and elastomers investigated for service with N_2H_4, only a few were found satisfactory for service, and only a very few were satisfactory for general use.

b.   Test Program

Following the literature survey, a test program was prepared. Table 53 is a tabulation of the materials tested and conditions of the test.

Metal and nonmetal tests with each propellant will be discussed in the following sections.

(1)   Nitrogen Tetroxide (N2O4)

(a)   Metals

Table 54 is a summary of the data obtained from tests of various metals with N_2O_4 at 60 ± 5 F for stated periods of time ranging from 30 to 63 days. These tests were conducted in 250 ml Erlenmeyer flasks fitted with inverted drying tubes filled with silica gel as shown in Figure 46. The ends of the drying tubes were sealed with polyethylene. Except where noted, three specimens of each metal placed in the flasks, in a manner providing minimum contact between specimens, were half submerged in approximately 100 ml of N_2O_4.

The specimens, most of which were approximately 1/2 x 3 x 1/16 inch, were degreased in fresh methylene chloride prior to initial weighing and immersion. Upon removal from the N_2O_4 at the end of the exposure period, only a few seconds of air agitation in the hood sufficed to allow any N_2O_4 to evaporate from the surface. The specimens were then hand scrubbed with a rubber stopper and in running water to remove any surface corrosion products prior to drying in a stream of dry nitrogen, and final weighing. Figures 47 and 48 are photographs of the metal specimens, taken after final weighing.

Of the 63-day exposure tests, only three alloys, 2014 aluminum, 5456 aluminum, and Haynes Stellite 6K, were exposed continuously throughout this period. The other five were exposed for an initial period of 30 days (see Table 54), rubber stopper scrubbed, dried,

weighed, and then re-immersed for an additional 33 days. It is probable that this double exposure, double scrubbing technique results in a higher percent weight change and corrosion rate experience than with a steady state 63 day exposure.

No corrosion rate is shown for AM 100A magnesium (30 days) or for Inconel (30 days) because the specimens increased in weight, with exposure to N_2O_4. This is probably due to difficulty in removing the corrosion products employing the rubber stopper scrubbing technique.

The titanium alloy, A110 AT, was removed from test after one week for safety reasons. References 62, 63, and 64 list incidents where titanium alloys and strong oxidizers have detonated under certain conditions with resultant loss of personnel and property. In order to investigate the reported pyrophoric tendency, a piece of A110 AT titanium, approximately 1 x 1/2 x 1/16 inch, was partially immersed in about 14 ml of N_2O_4 in a pyrex glass tube and sealed while frozen and under vacuum. The glass tube and specimen were positioned under an impact tester, and impact tested at 170 ft-lb after 29 days. Neither detonation nor gross reaction was evidenced, but microscopic examination of the specimen showed indications of a slight burning reaction. This was evidenced by a deep fan-shaped, blue discoloration and molten metal appearing on the face of the coupon. Figure 49 is a photomicrograph of the affected area. A control sample of 2024 aluminum also was impact tested with 170 ft-lb under identical conditions. As a second control, samples of titanium A110 AT was subjected to the same impact in air. Neither detonation nor evidence of burning was detected with both control samples. Figure 50 is a photograph of the three samples for comparison.

The importance of the sensitivity of titanium exposed to strong oxidizers is recognized by people in the missile industry. As a consequence, Wright Air Development Division (WADD) has contracted Allied Chemical Corporation, Nitrogen Division, to determine the impact sensitivity of commercially pure titanium, titanium alloy C 120 AV, and one other metal when exposed to liquid N_2O_4 and to determine the mechanism of the ignition, should this take place. In Reference 72, a summary of the first quarter, Allied Chemical stated that preliminary tests, conducted with pure titanium exposed to liquid N_2O_4 up to 336 hours, yielded no detonation nor violent reaction in the absence of foreign matter when the titanium was impact tested with 100 ft-lb force. In the presence of foreign matter such as impure sand, evidence of reaction was obtained when the titanium specimen was struck with a flat end pin with 100 ft-lb force. For further data, it is recommended that future Allied Chemical Corporation quarterly reports be reviewed.

The N_2O_4 used to conduct these tests was analyzed and met the purchase specifications. Only slight changes in analyses were found after testing. Specifically, water, the most important contaminant, increased from 0.11 (by weight) before test to 0.14 (maximum after test.

(b) Elastomers, Plastics, Asbestos-Filled Gasket Material, Graphite Materials, and Lubricants

Table 55 is a compilation of the data obtained in tests of various non-metallic materials in N_2O_4 at 60 ±5 F for stated periods of time ranging from 45 minutes to 63 days. The short-term tests were performed for the purpose of determining a satisfactory seal for short-term exposure during the seals and bearing tests (Phase III). The apparatus used was the same as for the metals (see Figure 46). Except where noted in the table, only one specimen of each material was tested fully immersed in about 100 ml of N_2O_4.

No pretreatment or cleaning was performed on specimens prior to initial weighing and immersion except for mechanical wiping with Kim-wipes. Most of the materials

exhibited absorption of the N_2O_4 to varying degrees, and upon removal from the N_2O_4 at termination of exposure, all were "out gassed" in the hood for at least 20 hours before final weighing and measurement.

Except for the silicone rubber O-ring covered with unplasticized Kel-F, all of the materials listed in Table 55 under elastomers exhibited gross swelling while immersed in the N_2O_4 and, in most cases, were measured immediately upon removal from the oxidizer. These measurements were used to calculate the "percent volume change before out gassing" values shown in the table. Similarly, the "after out gassing" values were calculated using the final volume measurements after out gassing.

All of the plastics tested showed dimensional stability both during and after immersion in the N_2O_4 and, with the exception of Raythene-N which was exposed twice as long as any of the others, apparently underwent no gross changes in physical properties or appearance. The Genetron samples, tested as possible material for lip seals, had been pretreated by compressing between platens heated between 450 and 500 F. The clear samples were amorphous in structure, having been quickly water-quenched whereas the cloudy samples were crystalline, having been allowed to cool down very slowly between the platens.

The lubricants were tested by smearing a small quantity of the grease on a weighed glass microscope slide, reweighing for the grease weight by difference, and positioning the slide at about a 45 degree angle in the 250 ml Erlenmeyer flask. The slide was half immersed in the N_2O_4, positioning the grease partly in the liquid and partly in the vapor. Upon removal after exposure and after 20 hours out gassing, the slide and grease were reweighed to determine the percent change in weight. These figures are not strictly comparable, however, because of varying degrees of purely mechanical loss of grease in handling.

It should be noted that none of these greases appear to be completely suitable for N_2O_4 service; all were grossly damaged by the N_2O_4.

(2) UDMH and N_2H_4

(a) Metals

Table 56 is a summary of the data obtained from test of various metals in UDMH at 140 F for one month. Tables 57 and 58 are similar summaries for tests of metals for one month in N_2H_4 at 140 and 200 F respectively. All of thse tests were conducted in 250 ml Erlenmeyer flasks fitted with condensers and placed in a constant temperature bath. Figure 51 is a photograph of the test set up.

Three specimens, approximately $3 \times 1/2 \times 1/16$ inch, of each metal were degreased with methylene chloride and placed in a flask in a manner providing minimum contact between specimens. Fuel in the amount of 100 ml permitted half submersion of the specimens. In the first group of tests, the open end of the condensers was covered loosely with a piece of aluminum foil and the ground glass joint was left dry. It was not anticipated that a serious breathing problem would result with this set up; however, as noted in Tables 56 and 57, the first group of tests showed considerable decomposition of the fuels.

The loss of strength of UDMH was probably caused by air oxidation characterized by the extensive discoloration which occurred. In the case of N_2H_4, however, moisture was probably the cause of the decreasing strength of the N_2H_4 and the forming of a hydrate with a somewhat higher specific gravity than anhydrous N_2H_4. This decomposition problem was investigated to some extent in the propellant decomposition section of this report.

It was believed that the condition of the fuels that existed at the end of the tests would present a more corrosive medium to the metals than with specification grade fuels. Based on this theory, it was concluded that metals not affected by the fuels in these tests would not be affected by the specification grade fuels. Work done at Food Machinery and Chemical Corporation, (Reference 69) with UDMH, showed negligible corrosion of most of these metals after seven days at 146°F. In their tests, there was little or no change in the UDMH assay. (It should be noted that there was little or no color change in the UDMH during the first six or seven days of the tests listed in Table 56.)

As further confirmation of the above theory, several tests were repeated with a modified test set up. These repeat tests are marked with a double asterisk in Tables 56 and 57.

In the new test set up, the open end of the condenser was sealed with a double layer of 3-mil thick polyethylene film and the ground glass joint between the condenser and the falsk was sealed with UDMH lubricant. The balance of the tests under this program were run with this sealed apparatus.

Several metals, as noted in Tables 56 and 57, were exposed to the fuels for an additional 94 days at 115°F. There was no further significant change in the specimens except for 6061 aluminum alloy which showed a slight discoloration of the metal exposed to the liquid N_2H_4.

Metal specimens were washed by hand in cold water, dried, and weighed at the end of the tests. Figures 52, 53, 54, and 55 are photographs of the various metal specimens after test.

(b)   Plastics, Elastomers, and Gaskets

Table 59 is a summary of the data obtained from tests of various plastics and elastomers in UDMH for one month at 140°F. Table 60 is a similar summary for N_2H_4.

Except for the butyl rubber, only one specimen of each material was exposed to the fuel.

Most of the materials exhibited absorption of fuels to varying degrees. At completion of the tests, specimens were rinsed in cold water and dried at a slightly elevated temperature (90-100°F) for several minutes. They were weighed within approximately one hour after removal from the fuel. Several specimens had absorbed UDMH to the extent that a weighing, even after one hour, was difficult. These, as indicated in Table 59, were reweighed after 48 hours. This situation was not so serious with N_2H_4.

A Gehman Stiffness Tester was used to determine the Apparent Modulus of Rigidity of several elastomers (Tables 59 and 60). The test procedure followed is explained in ASTM D1053-58T, "Measuring Low Temperature Stiffening of Rubber and Rubber-Like Materials by Means of a Torsional Wire Apparatus". It is estimated that the accuracy of the Modulus of Rigidity is ±10%.

Although many of these materials exhibited absorption of fuel and swelling, it should be noted that in many applications the area of material exposed to the fuel will only be a fraction of that area exposed during these tests.

(c) Lubricants

A number of lubricants were tested statically by smearing a small quantity of the lubricant onto a glass rod and half submerging it into the fuel. This test served only to eliminate those lubricants that dissolved in the fuel in a few hours. The bulk of the lubricant tests were performed on a dynamic lube tester designed at Bell Aerosystems (Figure 56).

The dynamic lubricant tester consisted of a cylinder approximately 2 x 2 inches with a piston. The piston shaft extended out either end of the cylinder and was moved through a two inch total travel by a motor and cam at the rate of three cycles per minute. The O-ring on the piston and the O-rings through which the shafts moved were covered with the lubricant in question. The cylinder was filled with fuel by means of a reservoir and bypass line. The linkage between the motor and tester was fitted with a strain gage feeding a signal to a Speed-O-Max recorder. The calibrated gage permits a recording of the force in pounds required to move the piston. An electronic timer was included to permit recording data for one minute every eight minutes. Each test ran approximately six hours, for a total of 1100 cycles.

Interpretation of the data obtained with the lube tester is dependent upon the following conditions:

(1) The force required to cycle the piston in the cylinder 1100 times (The 1100-cycle value is based upon experience gained by Bell Aerosystems Company).

(2) The condition of the piston and shaft O-rings at the end of a test.

(3) The force required to free the piston from the cylinder wall after having set idle for several hours.

Figure 57 is a graph showing the data for these tests with UDMH and N_2H_4. Smooth curves were drawn through the data from the Speed-O-Max recorder chart. Table 61 is a list of the lubricants showing the condition of the O-rings at the conclusion of the tests, as well as the restart forces. These various lubricants tested can be compared to the UDMH lubricant currently being used on the Bell Aerosystems rocket engines which employ UDMH as a fuel.

Two other items to be determined before a lubricant can be definitely recommended for use with UDMH, or as a matter of fact any other fuel, are:

(1) Its compatibility with the flush liquid

(2) A functional test on a component

Two of the lubricants, S-#58-M and Lox-Safe, were successfully tested in methanol which is the flush liquid currently used at Bell. The UDMH lubricant has been found satisfactory with methanol.

Preliminary functional tests on a gas generator propellant valve indicated satisfactory timing sequences, and although O-ring rolling occurred with the two test lubricants, no leakage was detected. Part of the rolling problem may have been caused by a long time delay between the start and finish of one of the tests.

It should be noted at this point that of the many lubricants tested at Bell Aerosystems and at other installations none has been found to be perfectly satisfactory with UDMH. The usual problem is excessive solubility. The lubricants reported, herein, represent most of the better lubricants tested. It should also be noted that in the case of N_2H_4, which has a much lower solvent action than UDMH, there are a number of suitable lubricants. Consequently the lubrication problem with N_2H_4 is much less serious than with UDMH.

(d)   Miscellaneous Tests

There were several additional tests performed during the past year that are belived worthy of inclusion in this report. Most of them were for the purpose of solving an immediate problem, and as a result, the tests were not as extensive as those tabulated elsewhere in this report.

Genetron H L plastics (made by General Chemical Company) was tested in UDMH for two weeks at ambient temperature (70-75 F). A small piece of very thin sheet stock was immersed in UDMH. No change in the material was noted at the end of this period.

Epon 815, an epoxy plastic made by Shell Chemical Corporation, was tested in UDMH for ten days at ambient temperature. After one day there was a slight loss in weight. Witnin ten days, the specimen was completely dissolved.

Reythene-N, an irradiated blend of polyethylene and other polyolefins, was immersed in UDMH for approximately two months at 110-115 F. No apparent change in the specimen was noted at this time. During the first two weeks, the UDMH extracted some dye from the specimen. This was apparently some excess dye because there was no significant visual change in the black color of the sample.

Two samples of Genetron, G.C.X.-3B, one crystalline in structure and one amorphous (see processing details under section on N_2O_4 above), were tested in UDMH for 20 days at 140° F. At the end of this time the laminants on the amorphous sample started to separate and the crystalline sample became brittle. Both samples were dark brown in color, as was the UDMH.

Tables 62, 63, and 64 are summaries of the compatibility data, obtained under this contract, for materials of construction with UDMH, N_2H_4, and N_2O_4, all in an anhydrous state. Table 62 lists the materials found satisfactory for use with the propellants under the test conditions described. Table 63 lists the materials that are satisfactory for short-term service with the propellants, and Table 64 lists the materials that are unsatisfactory for service with the propellants.

The latest material compatibility data, obtained from the literature and appearing in Tables 44, 47, and 50 show conflicting test data. For example, A-nickel in N_2O_4 at 60 ±5° F for 63 days tested at Bell yielded a corrosion rate of 0.013 mil per year, whereas Rocketdyne (Reference 68) lists nickel as incompatible with N_2O_4 at ambient temperature. Other conflicting data are evident with 17-7 PH stainless steel in N_2O_4, 316 stainless steel in UDMH and N_2H_4, Monel in UDMH, type 1100 aluminum, Inconel, and 304 stainless steel in N_2H_4.

B.   PHASE III — SYSTEM AND COMPONENT ANALYSIS

1.   Fluid Flow Data

After a preliminary analysis of the flow chambers of the valves that were selected for the system flow tests (this included investigating existing Rascal* test data), it was determined to subject these valves to individual calibration tests to establish flow characteristics.

This was accomplished in the storable propellant flow system (Figure 58) by using substitute test fluids, methanol for UDMH, and methylene chloride for N_2O_4. Flow versus pressure drop values were established to cover the expected operating range of the flow system. The results of these flow tests are stated in Tables 65 through 75 under room temperature acceptance tests.

Data recorded included supply tank pressure, flow rates, and pressure drops at a flow rate ranging from rated to 30% of rated. An average of five points was recorded and plotted. Using recorded flow data, curves were plotted for an equivalent flow of water to simplify the conversion of the flows to any other liquid propellant (Figures 59 through 68).

Following rated flow acceptance tests, the system was drained of test fluids and purged with nitrogen and refilled with the actual propellants.

See Systems Analysis Section for propellant flow data.

2.   Solubility of Pressurizing Gas

The literature survey did not reveal experimental information on solubility of pressurization gases and composition change of the propellants during expulsion. However, experience at Rocketdyne (Reference 22) and Aerojet-General (Reference 21) show that pressurizing propellants with nitrogen gas have no effect on the propellant quality. Jet Propulsion Laboratory (Reference 30) has pressurized N_2O_4 and N_2H_4 with both nitrogen and helium and have experienced no effect on the propellant burning qualities. The vendors (References 32, 33, and 42) also transfer the propellants with nitrogen gas and have not encountered changes in the propellant quality attributable to the nitrogen.

Solubility experiments were determined by loading a given volume of propellant into one of two cylinders separated by a valve and fitted with a pressure gage, and charging the other to a given pressure with gas. With gas and propellant at constant temperature, the connecting valve is opened allowing the gas to pressurize the propellant. By shaking the apparatus periodically, good contact is insured and the gas is given an opportunity to dissolve in the liquid. From a record of pressure changes with time, the solubility of the gas in the propellant is calculated for the temperature under which the test was made. The apparatus is then subjected to another temperature and a second set of readings is taken. More specific details are afforded by describing a particular experiment with reference to Figure 69.

The propellant cylinder is fitted with a cross containing a 150-psig burst disc assembly, a 100-psig pressure gage, and a hand valve. The gas cylinder is fitted with a cross containing 100-psig pressure gage, a hand valve, and a line to the other hand valve. Both cylinders are then connected through this valve. A cylinder of the gas to be investigated is connected to the other hand

*The components used in this test program are from the LR67-BA-9 rocket engine, developed by Bell Aerosystems Company for the Rascal missile project under Air Force contract. Specific components are identified herein by drawing numbers.

valve, and the system pressure checked. After all leaks are eliminated at 100 psig, the valve between the cylinders is closed. Then, the gage of the propellant cylinder is removed and the cylinder half filled with a known weight of propellant. The gage is replaced, the common hand valve opened, and pressure readings taken as previously described for at least four hours. The apparatus is then subjected to a different temperature and another series of readings taken with due allowance for attainment of thermal equilibrium. To be significant in terms of the accuracy of the gages employed, pressure differences must be greater than 0.5 psig. The accuracy of the gages is considered to be ±1%. This total pressure difference corresponds to the accuracy shown in Table 76 for each measured solubility.

Gas solubility is calculated according to the equations

$$S = \frac{\Delta w \; 100}{\text{Weight of Propellant}}$$

$$\Delta w = w_1 - w_2$$

$$w = \frac{PVM}{RT}$$

Where:
P = gas pressure in atmospheres, absolute

V = gas volume in liters

M = molecular weight of pressurizing gas

R = gas constant (0.082)

T = absolute mean temperature

w_1 = weight of gas in system at start of test

w_2 = weight of gas in system at end of test

S = solubility of gas in liquid in weight %

Example of calculations taken from Run No. 3

Total gas weight in system at start of test is determined as follows:

w_1 = weight of gas in gas cylinder + weight of gas above propellant

$w_1 = \frac{PVM}{RT}$ (initial pressure, volume and temperature)

$$= \frac{(7.60)\,(0.671)\,(4)}{(0.082)\,(298)} = 0.8348 \text{ gm He}$$

$$\begin{array}{l} 0.8348 \\ \underline{0.0389} \quad \text{weight of gas above propellant} \\ 0.8737 \quad \text{gm total weight of He} \end{array}$$

Total gas weight undissolved in system at the end of test is determined as follows:

$w_2 = \frac{PVM}{RT}$ (final pressure, volume and temperature)

$$= \frac{(5.39)\,(0.968)\,(4)}{(0.082)\,(298)} = 0.8540 \text{ gm undissolved He}$$

Gas solubility is calculated as follows:

$$\triangle w = w_1 - w_2$$

$$\triangle w = 0.8737 - 0.8540$$

$$\triangle w = 0.0197$$

$$S = \frac{\triangle w \; 100}{\text{Weight of propellant}}$$

$$S = \frac{0.0197 \times 100}{296.5}$$

$$S = 0.007\% \pm 0.005\%$$

Accuracy

Vary the final pressure 5.39 atmospheres by ± 0.1

Then w_2 becomes 0.8700 and 0.8390

And S varies $\pm 0.005\%$

The data in Table 76 indicates that nitrogen and helium show a slight increase in solubility with increase in temperature over the range studied for the three propellants under consideration. Actually, the solubilities of the gases in UDMH and N_2H_4 are very low.

In general, the gases are more soluble in N_2O_4 with nitrogen again being more soluble than helium.

3.   Propellant Handling

Propellant handling information for N_2O_4, UDMH, and N_2H_4 was incorporated in the Bell Aerosystems Company, "Space Flight Division Safety Rules and Regulations", revised 30 March 1959. The following section contains this information as well as information obtained during the performance of testing under this contract. In addition, references are made to the literature which contain pertinent propellant handling data.

a.   Nitrogen Tetroxide

Nitrogen tetroxide is an equilibrium mixture of nitrogen tetroxide and nitrogen dioxide ($N_2O_4 \rightleftharpoons 2NO_2$). The physical properties of this oxidizer are reported in Table 1.

In the solid state, pure N_2O_4 is colorless. In the liquid state, the equilibrium mixture is yellow to red-brown, and in the gaseous state, red-brown. The fumes exhibit a characteristic pungent and irritating odor.

N_2O_4 is hypergolic with such fuels as UDMH, N_2H_4, aniline, and others and reacts with water forming nitric and nitrous acid. The nitrous acid undergoes decomposition immediately forming additional nitric acid and evolving nitric oxide $(NO)X$ (Reference 13). N_2O_4 is soluble and compatible with methylene chloride which was used for flushing N_2O_4 systems.

(1) Health Hazards

Liquid N_2O_4 spillage on the skin or splashing in the eyes causes burns similar to that caused by 65% nitric acid. Brief contact of the liquid with the skin or other tissues results in

yellow staining; if the contact is more than momentary, a severe chemical burn results. If splashed in the eyes, N_2O_4 may cause blindness. If it is swallowed, the internal burn may be sudden and severe, resulting in death (Reference 58).

N_2O_4 vapors are very toxic. Inhalation of these vapors is normally the most serious hazard in the handling of N_2O_4.

The maximum allowable concentration (MAC)* of this vapor is expressed as five parts of NO_2 per million parts of air (2.5 ppm as N_2O_4) (Reference 74). Dr. Leslie Silverman (Reference 76) of the Harvard Medical School of Public Health has suggested that the MAC value for a ten minute period can safely be exceeded by a factor of 5. Also, Dr. E.C. Wortz (Reference 78) of the Martin Company, Denver has compiled data for short term exposures to N_2O_4 and concludes that for a ten minute period, the MAC value for N_2O_4 also may be exceeded by a factor of 5. The Nitrogen Division of Allied Chemical (Reference 75) reports that an individual exposed himself to 158 ppm of NO_2 for ten minutes without showing adverse after effects. This value exceeds the MAC by a factor of 30. It would indicate that Dr. Silverman's and Dr. Wortz's data are safe values for short term exposures.

The main danger of acute poisoning with NO_2 is the development of pulmonary edema, the filling of the lungs with fluid, with resultant reduction of the ability of the lungs to transport oxygen. This condition normally develops considerably later than the exposure to the fumes. The initial symptoms, irritation of the eyes and throat, cough, tightness of the chest, and nausea, are slight and may not be noticed. Later, severe symptoms begin; their onset may be sudden and precipitated by exertion. Cough, feeling of constriction in the chest, and difficult breathing occur. Cyanosis (a blue tinge to the mucous membranes of the mouth and eyelids, and lips and fingernail beds) may follow. Persons with such symptoms are in great danger. Milder cases may show signs of bronchitis with cyanosis; others, nausea, abdominal pain, and vomiting (Reference 13).

(2)   First Aid

If N_2O_4 liquid or vapor comes in contact with the skin, immediately wash with copious quantities of water. If splashed into the eyes, they should be flushed with water continuously for 15 minutes with a fellow employee assisting the injured by holding the eye open, if necessary. Medical assistance should be summoned immediately. Administration of anything else such as neutralizing agents should be done only at the direction of a physician.

Persons exposed to N_2O_4 fumes should be removed from contaminated area immediately. Patient should be carried and not allowed to walk since exertion increases the effects of pulmonary edema. Administration of oxygen by properly trained persons is usually desirable. Those known to have been seriously exposed should be removed to a hospital.

Swallowing of N_2O_4 should be promptly treated by drinking large amounts of water (or milk if it is readily available) and medical attention sought at once.

(3)   Fire and Explosion Hazards

N_2O_4 alone, will not burn but its vapors will support combustion. If fire supported by N_2O_4 occurs, shut off the N_2O_4 supply, if possible, and extinguish the fire by using an extinguisher compatible with the burning material.

*These represent values to which man may be exposed for a normal working day, day after day without adverse effect.

Nonhypergolic rocket fuels are a potential explosion hazard when mixed with N_2O_4. N_2O_4 of commercial purity is stable at ordinary temperatures and can be safely stored in moderate pressure vessels. It is stable to all types of mechanical shock and impact.

N_2O_4 must be stored and handled in well ventilated areas remote from fuels.

(4) Handling

Personnel handling H_2O_4 must wear protective clothing. In general, rubber suits, boots, and gloves made of GRS rubber may be used with reasonable safety if contamination is washed off immediately. Hoods made of material compatible with N_2O_4 are recommended (polyethylene, GRS rubber). Other recommended protective clothing are:

(a) Gloves - vinyl coated, type R-1 under Specification MIL-G-4241, Reference 13

(b) Gloves - Bluettes, duPont neoprene rubber, Pioneer Rubber Company, Willard, Ohio

(c) Gloves - Edmont, Cadet style, 7897, Edmont Inc., Cushocton, Ohio

(d) Vinyl-coated fiberglass - inner type NA-1, Specification MIL-S-4553 (USAF), Reference 13

(e) Suit Material - Specification MIL-S-12525 (QMC), Reference 13

Frequent inspection should be made of all protective clothing to detect flaws which might result in personal injury.

Should it be necessary to enter an area where a high concentration of N_2O_4 vapor is present, a self-contained air source, such as a Scott Air-Pak, should be worn. An adequate water supply must be available for flushing and decontamination and for personnel showers and eye baths. Silica gel canister will remove 80% of oxides of nitrogen and provides protection for five times the MAC (Reference 76).

If leaks or spills are detected, they should be dealt with by employees who are provided with adequate personal protective equipment. The N_2O_4 must be flushed away at once with large amounts of water.

An accidental spillage of 165 gallons of N_2O_4 was experienced during a pump test under this contract. At the time of the spillage, when a 2-inch line ruptured, personnel were not in the cell. Personnel in the area downstream of the prevailing winds were warned to stay under shelter until the NO_2 fumes had dissipated. Floor floods in the cell were turned on. Damage to the cell consisted of mild steel attack and instrumentation damage. The concrete floor was not visibly attacked. No one was allowed in the cell until the next morning when this line was capped to prevent the remaining N_2O_4 in the 300 gallon tank from vaporizing. Personnel who were exposed to any NO_2 fumes were examined by the plant doctor the next day. Aside from slight eye and throat irritation, the men were judged physically fit.

N_2O_4 can be shipped only in high pressure seamless steel cylinders or tank cars. The N_2O_4 is received at Bell Aerosystems in one-ton mild steel cylinders. Before transfer, the cylinder and its contents must be cooled to between 32 and 50° F. After cooling, remove the pro-

tective cap and plug, then install an adapter on the threaded opening. This adapter should be made of stainless steel (300 series) for continued service. The cylinder is placed in a horizontal position with the cylinder valves in the vertical centerline. So located, gaseous N_2O_4/NO_2 can be drawn from the top valve, liquid N_2O_4 from the bottom valve. If more pressure is required to transfer liquid N_2O_4, nitrogen or compressed dry air may be used as the pressurizing medium (Reference 9).

Unloading of a tank car into a storage tank may be accomplished by dry compressed air, by transfer pump, or by dry compressed inert gas. The suppliers of N_2O_4 will furnish more specific instructions for the proper unloading of tank cars. Before charging any system with N_2O_4, it is important that the storage tank, all pipe lines, valves, and fittings are free of oil, other organic materials, scale, foreign matter, and traces of water. If any part of the system contains moist air it should be flushed thoroughly with dry compressed air or dry compressed inert gas before charging is begun.

Specific transfer operations for small and large quantity transfers are explained in the body of this report.

Every possible precaution should be taken in handling containers to avoid damage which might cause leaks.

(5)   Disposal

Small quantities of N_2O_4 should be vented slowly outdoors. Large quantities may be disposed of by draining slowly below the surface of water forming nitric acid which can be neutralized with an alkali such as sodium hydroxide. This neutralization should take place prior to dumping into a waterway. In addition, large quantities may be disposed of by burning with a fuel such as kerosene.

b.   Unsymmetrical Dimethylhydrazine (UDMH)

UDMH is a clear, colorless, fuming, hygroscopic liquid with a rather sharp ammonia or fishy odor generally characteristic of organic amines. The odor of these vapors appears to offer adequate warning of acute exposure to dangerous concentrations (Reference 77). The physical properties of this fuel are reported in Table 1.

UDMH is hypergolic with strong oxidizers such as N_2O_4 and fuming nitric acid. It reacts very slowly with air at ambient temperature to form traces of air oxidation products which imparts a yellow color to the propellant. However, this condition will not result if the UDMH is maintained under a nitrogen blanket. UDMH is soluble in water, methylene chloride, ethanol, methanol, and most petroleum fuels.

(1)   Health Hazards

The MAC for UDMH is 0.5 ppm, but for short-term exposure, Dr. Silverman (Reference 76) suggested that the MAC value for a 10-minute period can be safely exceeded by a factor of 10. However, Dr. Wortz has calculated data (Reference 78) to show that the MAC value may be exceeded by a factor of 5. Dr. Wortz's data might be considered to be a safe exposure limit.

In sufficient amounts, UDMH is toxic by inhalation, ingestion, and skin contact producing several significant systemic effects. In addition, it produces local irritating effects upon the eyes and the respiratory tract. UDMH has little or no local effect on the skin but is readily absorbed into the body by this route.

Knowledge of the systemic effects produced by the compound is confined almost entirely to that obtained from animal experiments. Short exposures effect the central nervous system resulting in hyperpnea, convulsions, and possibly death. Repeated or chronic exposures produce toxic damage to the liver and kidneys which more probably would result in death.

Experience with human exposure to N_2H_4 and UDMH is limited, but cases of delayed and possibly cumulative conjunctivitis have been reported among men in plants manufacturing N_2H_4. These employees also complained of nausea, dizziness, and headache. The occurrence of dermatitis among such personnel was reported.

(2) First Aid

Splashed skin areas should be washed copiously with water. The eye, if contaminated, should at once be flushed copiously and thoroughly, with clean water.

A person suspected of UDMH vapor poison should leave the contaminated area and breathe deeply of fresh air.

If UDMH is taken internally, induce vomiting.

Individuals who have been overexposed should be examined by a physician. Regular handlers should be examined by a physician periodically.

(3) Fire and Explosion Hazards

The lower limit of flammability of UDMH in air at one atmosphere is 2.3 by volume at 5 F. Below this limit, there is insufficient UDMH for combustion. The upper limit of UDMH in air at one atmosphere is approximately 92 by volume at 212 F. Flame did not propagate through UDMH vapor in the absence of air at one atmosphere (Reference 15).

If fires occur, water in large quantities should be used to extinguish them. UDMH will not burn when diluted with 2 to 3 times its volume of water. The U.S. Bureau of Mines reported that 53 parts by volume water plus 47 parts by volume UDMH at ambient temperature (70 F) will not burn (Reference 79).

UDMH vapors can be exploded by an electric spark or an open flame but liquid UDMH is insensitive to shock or friction.

UDMH should be stored in sheltered, well-ventilated areas separated physically from oxidizer storage areas. Open-side buildings would be satisfactory. UDMH containers should be grounded. Electrical equipment of all types, in the area, should be vapor tight and explosion proof. Running water, hoses, and floor drains should also be provided.

(4) Handling

Personnel handling UDMH must wear protective clothing. In general, rubber suits, boots and gloves, and hoods will suffice. The protective clothing listed in the N_2O_4 section is satisfactory for use with UDMH.

Should it be necessary to enter an area where a high concentration of UDMH vapor is present, a self-contained air source, such as a Scott Air-Pack, should be worn. For 30 minutes, a canister type protective breathing apparatus is effective for contamination levels up to 10,000 ppm (Reference 76).

If leaks or spills are detected, they should be dealt with by employees who are provided with adequate personal protective equipment. Dilution with copious quantities of water and flushing down drains into catch basins should be carried out as soon as possible.

Large quantities of UDMH should be transferred in clean, closed metal systems. The UDMH should be blanketed with nitrogen at all times.

At Bell, UDMH transfers are made from the receiver drums (55 gallons capacity) to cell tanks by means of an Eco pump. This is a positive displacement pump made of stainless steel with a glass impregnated Teflon impeller. The pump is capable of pumping 10 gallons per minute. Prior to pumping, the drum of UDMH is grounded to the pump which in turn is grounded to the valve fill line. On occasion, drums are emptied by gravity flow or pressurized with nitrogen to 2 psig with a pop safety valve used to insure against over-pressurization. Before discarding, the empty drum should be flushed thoroughly with water to remove any remaining small amount of UDMH. For drums being only partially emptied, the most conservative practice is the maintenance of an atmosphere of inert gas with vapor space as the contents are withdrawn.

Tank cars loaded with UDMH are equipped with a standpipe through which the contents are removed. Discharge of the car contents can be achieved by pressurization with an inert gas,such as nitrogen, or by pumping. Priming of the pump can be accomplished by either nitrogen pressurization or other acceptable priming practices (Reference 13).

(5) Disposal

Because UDMH in water can have adverse effects on fish and animals, it should not be added deliberately to drainage ditches or ponds. Bulk quantities should be collected in suitable containers for burning. When UDMH enters drainage systems by accident, it must be reduced to safe limits by addition of a chemical which will decompose the UDMH (Reference 80).

A research program was carried out in the Bell Aerosystems' Propellants Laboratory to find methods for determining small quantities of UDMH and/or N_2H_4 in waste water and destroying them by chemical means. One ppm can have adverse effects on fish (Reference 82).

Hypochlorite was found to effectively destroy both UDMH and N_2H_4. The factors for destruction of both UDMH and N_2H_4 using 100% calcium hypochlorite have been worked out and are as follows:

(a) UDMH factor $=$ 0.00128 oz/ppm/gal

(b) N_2H_4 factor $=$ 0.00256 oz/ppm/gal

The calculations for determining the amount of hypochlorite necessary for destruction of UDMH and/or N_2H_4 in a waste pond are as follows:

$$\frac{\text{Capacity of pond x ppm UDMH or } N_2H_4 \text{ found x factor (oz/ppm/gal)}}{16} = \text{lb of } 100\% \ Ca(C10)_2 \text{ needed}$$

At Bell Aerosystems Company, the aforementioned methods are in use at the present time with one exception; 70% calcium hypochlorite is used in place of 100%. It is purchased under the brand name HTH from Olin Mathieson Chemical Corporation.

The pond is checked twice daily for the UDMH and/or N_2H_4 content.

c.   Hydrazine (N_2H_4)

N_2H_4 is a clear, colorless, hygroscopic liquid with an odor similar to that of ammonia. Its high performance and high density make it an excellent fuel. The physical properties of N_2H_4 are reported in Table 1.

N_2H_4 is a strong reducing agent and a weak chemical base. It will react with carbon dioxide and oxygen in air. It is hypergolic with such oxidizers as N_2O_4, fuming nitric acid, chlorine trifluoride, liquid fluorine, and hydrogen peroxide.

When N_2H_4 is exposed on a large surface to air, such as on rags, it may ignite spontaneously due to the evolution of heat caused by oxidation with atmospheric oxygen. A film of N_2H_4, in contact with metallic oxides and other oxidizing agents, may ignite (Reference 13).

N_2H_4 will decompose spontaneously in a similar way to hydrogen peroxide. The reaction of N_2H_4 with the oxides of copper, manganese, iron, silver, mercury, molybdenum, lead, or chromium may be particularly violent (Reference 13).

N_2H_4 is soluble in water in all proportions and in low molecular weight alcohols. It is insoluble in JP-4 and methylene chloride.

(1)   Health Hazards

The MAC for N_2H_4 is 1.0 ppm but for short-term exposure, Dr. Silverman (Reference 76) suggested that the MAC value for a 10-minute period can be safely exceeded by a factor of 10. However, Dr. Wortz has calculated data (Reference 78) to show that the MAC value may be exceeded by a factor of 5. Dr. Wortz's data might be considered as safe exposure limits.

Anhydrous or aqueous solutions of N_2H_4 are toxic by contact with the skin, inhallation with vapors or by ingestion producing several systemic effects. In addition, N_2H_4 produces local irritating effects upon the eyes and the respiratory tract.

When N_2H_4 comes in contact with the skin, there is a burning sensation similar to an alkali-like burn. When vapors are inhaled, dizziness and nausea follow within a short time after exposure. When vapors attack the eyes, a delayed action is noted. Some hours later, the eyes become inflamed, swollen, and discharge pus. Temporary blindness may set in. Oral intake causes upset stomach and nausea (Reference 80).

(2)   First Aid

If N_2H_4 is taken internally, egg whites or other emollient, followed by a 5% saline solution or other mild emetic, should be administered immediately. A physician should be called at once and the patient kept as quiet as possible.

Individuals who have been over exposed to N_2H_4 vapors should be examined by a physician. Regular handlers should be examined by a physician periodically.

Liquid N_2H_4 is corrosive to body tissues and must be removed promptly by washing with a large quantity of water. The affected areas should be treated for alkali burns. If N_2H_4 comes in contact with the eyes, a physician should be called while the eye is being flushed with copious quantities of clean water (Rerference 17).

(3) Fire and Explosion Hazards

N_2H_4 is flammable both in the liquid and vapor state. Vapors are flammable in air in all concentrations above 4.67% by volume at 205 ±8° F (Reference 81). Even with nitrogen as diluent, N_2H_4 forms inflammable mixtures above 38% (Reference 16). Solutions containing more than 60% water will not flash when in contact with a flame (Reference 79).

N_2H_4 may be expected to undergo decomposition under appropriate conditions with the release of considerable energy. The decomposition of N_2H_4, catalyzed by metallic oxides such as iron, molybdenum, copper, lead, manganese, silver, mercuric, and chromium, may be violent and cause an explosion or a fire. In the absence of decomposition catalysts, liquid N_2H_4 may be heated above 500° F with very little decomposition (Reference 13).

N_2H_4 vapor can be detonated by a spark, and the vapor propagates detonation within the flammability limits. The autoignition temperature of N_2H_4 blanketed with air in stainless steel is 313° F, but blanketed with nitrogen, no ignition was noted up to 7800° F (Reference 16).

N_2H_4 fires are of the fuel type (or fuel and oxidizer type). For fuel fires, water is the most effective extinguishing agent. It cools the N_2H_4 while at the same time diluting it. A mixture of three parts water and two parts N_2H_4 will not burn. Because of the wide flammable limits and reignition hazard of N_2H_4, vaporizing liquids, powders, water fog, and foams are not as effective as water dilution in controlling this type of fire (Reference 13).

For flare type fires with fuel and an oxidizer, water is also the most effective agent where acceptable for the specific oxidizer present.

(4) Handling

Personnel handling N_2H_4 must wear protective clothing. In general, rubber suits, boots and gloves, and hoods will suffice. The protective clothing listed in the N_2O_4 section is satisfactory for use with N_2H_4.

Should it be necessary to enter an area where a high concentration of N_2H_4 vapor is present, a self-contained air source, such as a Scott Air-Pack, should be worn. For periods of 30 minutes, a canister type of protective breathing apparatus is effective for contamination levels up to 10,000 ppm of N_2H_4 (Reference 76).

If leaks or spills are detected, they should be dealt with by employees who are provided with adequate personal protective equipment. Dilution with water and flushing down drains into catch basins should be carried out as soon as possible. Before release from a catch basin, the N_2H_4 must be reduced to safe limits by chemical means.

Drum quantities (55 gallon capacity) of N_2H_4 are unloaded in the same manner as the UDMH transfers by pumping, gravity flow, or pressurization with nitrogen. Again, prior to pumping, the drum of N_2H_4 is grounded to the pump which in turn is grounded to the valve fill line. Empty drums should be filled with water, drained, and the bung replaced prior to setting aside for storage or return to the manufacturer. As a precautionary safety measure, maintain an atmosphere of nitrogen over the N_2H_4 at all times and purge transfer lines and the container receiving the N_2H_4 with nitrogen prior to transfer.

In general, normal acceptable practices for unloading tank cars of combustible liquids apply. Tank cars loaded with N_2H_4 are equipped with a standpipe through which the con-

tents shall be removed. Discharge of the car contents can be achieved by pressurization with nitrogen or by pumping. If pumping is used, nitrogen must be bled into the top of the tank car to prevent any atmospheric oxygen from entering. After being emptied, the tank car must be thoroughly flooded with nitrogen, capped, and returned (Reference 13).

(5) Disposal

Because N_2H_4 in water can have adverse effects on fish and animals, it should not be added deliberately to drainage ditches or ponds. Bulk quantities should be collected in suitable containers for burning. When N_2H_4 enters drainage systems by accident, it must be reduced to safe limits by addition of a chemical which will decompose the N_2H_4 (Reference 80). (See disposal section under UDMH for chemical treatment.)

d. Detection Devices

Portable devices for measuring oxides of nitrogen are manufactured by Mine Safety Appliance Company of Pittsburgh and Union Industrial Equipment Corporation of Port Chester, New York. MSA also manufactures portable kits for UDMH. There is no portable equipment available for measuring N_2H_4 contamination. The devices listed in the aforementioned are recommended for measurement of contamination in the 0 to 1500 ppm range (Reference 76).

The Kruger Instrument Company manufactures a recording device for measuring contamination levels of oxides of nitrogen. MSA will manufacture a device which can be connected to recording equipment and warning devices and which can detect UDMH, N_2H_4 or NO_2 in the toxicity range (Reference 76).

Where an explosive hazard exists, explosimeters manufactured by MSA, Davis Engineering Company of Newark, and others, are adequate for detecting contamination levels between one and five percent (Reference 76).

Recently it was learned that Micro-Path Incorporated has marketed portable devices which are capable of detecting oxidizers and fuels in concentrations as low as one ppm to 1000 ppm. The devices are called the Austin Remote Alarm Gas Detector, one Model (3055) capable of detecting NO_2 and another Model (3050) capable of detecting fuels such as UDMH or N_2H_4 (Reference 83).

These devices are currently under evaluation and their presence in this report does not constitute a recommendation.

4. Pumping Parameters

a. Seal and Bearing Evaluation

During this program, eight seal configurations of various construction and material were evaluated in liquid N_2O_4. The seal evaluation was made with a seal test fixture (Figure 70) mounted on a 10 HP vari-drive (Figure 71).

In addition, four bearing configurations, a ball bearing, roller bearing, and two sleeve type bearings, were evaluated. The bearing tests were conducted in a modified seal test fixture as shown in Figure 72. The fixture was also mounted and driven by the 10 HP vari-drive as mentioned previously. A summary of the test results are tabulated in Table 77.

(1)   The first seal was a Sealol Seal No. A-16353. This seal consists of a type 347 stainless steel welded bellows, cup, and end pieces. The seal face insert (2.251-inch OD and 1.530-inch ID) was glass impregnated Teflon (Figure 73) operating against a rotating type 316 stainless steel mating ring (Figure 74). The seal face rubbing velocity during these tests was 109 ft/sec at 14,000 rpm shaft speed. The propellant pressure was 95 psig. The following leakage rates were recorded. All leakage rates are reported in cubic centimeters per minute (cc/min).

Run No.	Run Time Seconds	Prerun Static Leakage cc/min	Dynamic Leakage cc/min	Postrun Static Leakage cc/min
515	60	50	150	50
517	120	50	115	5
518	180	5	100	75
519	240	75	87.5	100
520	300	100	64	0

Postrun inspection showed the seal and test fixture hardware to be in very clean condition. The sealing faces showed excellent smooth contact pattern with only minute wear on the glass impregnated seal face. This test also served the purpose to check out the cell system. Figures 73 and 74 are photographs taken after the test.

(2)   The second seal configuration evaluated was a Sealol Seal No. MFC-20JOB-22 (2.126-inch OD and 1.410-inch ID). This seal consists of an AM350 stainless steel (a precipitation-hardening alloy) welded bellows, cup, and end pieces. The seal face insert is Graphitar G-39 carbon (Figure 75) operating against a type 316 stainless steel mating ring (Figure 76). The seal face rubbing velocity was 105 ft/sec at 14,000 rpm shaft speed. The propellant pressure was 85 psig. The following leakage rates were recorded:

Run No.	Run Time Seconds	Prerun Static Leakage cc/min	Dynamic Leakage cc/min	Postrun Static Leakage cc/min
521	60	0	0	0
522	120	0	0	0
523	180	0	0	0
524	240	0	0	0
525	400	0	0	0
526	400	0	1 cc/400 sec	0
527	400	0	1 cc/400 sec	0
528	400	0	1 cc/400 sec	0

Postrun inspection showed the seal and test fixture hardware to be in very clean condition with no sign of chemical attack. The carbon face was in excellent condition and the type 316 stainless steel mating ring showed superficial scuff marks on the mating surface. Figures 75 and 76 are photographs taken after the test.

A repeat test was conducted with this seal. The seal was relapped and installed in the test rig with a new type 316 stainless steel mating ring (Figures 77 and 78, photographs taken

after test). The test conditions were the same except the propellant pressure was increased to 135 psig. The following leakage rates were recorded:

Run No.	Run Time Seconds	Prerun Static Leakage cc/min	Dynamic Leakage cc/min	Postrun Static Leakage cc/min
529	60	0	0	0
530	120	0	0	0
531	180	0	3	3
532	240	3	10	3
533	400	3	6	0
534	60	0	0	0
535	400	0	5	0
536	400	0	2	0
537	400	0	5	0
538	400	0	7	0

Postrun inspection showed the carbon seal face and bellows to be in excellent condition with little visible wear to the face. The mating ring displayed a very smooth wear contact pattern. No scuff marks were present on the mating ring as on the previous test run at 85 psig fluid pressure.

(3) The third seal configuration evaluated was a Sealol Seal No. A-18528 (2.126-inch OD and 1.468-inch ID). This seal consists of Graphitar G-39 carbon seal face insert with a butyl rubber chevron internal static seal packing. The skirt and seal housing are 300 series stainless steel. Figure 79 shows the carbon seal face insert after test. The mating ring material was nitralloy (Figure 80, photograph taken after test). This seal was tested for 23 minutes and 20 seconds in one day at 14,000 rpm shaft speed and 135 psig fluid pressure. The seal face rubbing velocity was 105 ft/sec. The evaluation was stopped until the following day. The next day, during the prerun static pressure check, the seal failed. Postrun inspection showed that the butyl rubber packing in the seal had deteriorated due to attack of N_2O_4 fumes during overnight shutdown. Note, in Figure 81, the flow of butyl rubber sealant. The sealing faces showed excellent wear patterns. The following leakage rates were recorded:

Run No.	Run Time Seconds	Prerun Static Leakage cc/min	Dynamic Leakage cc/min	Postrun Static Leakage cc/min
539	60	3	17	0
540	120	0	3	2
541	180	2	2	0
542	240	0	4	0
543	400	0	4	0
544	400	0	3	0

(4)   The fourth seal to be tested was Sealol Seal No. A-19169 (2.126-inch OD and 1.410-inch ID), a bellows type face seal with antirotation locks. This seal consisted of a G-39 Graphitar carbon face, 0.006-inch thick, type 410 stainless steel bellows, and 300 series stainless steel cup and end pieces (Figure 82, photograph taken after test). The mating ring was type 316 stainless steel (Figure 83, photograph taken after test). The seal face rubbing velocity was 105 ft/sec at 14,000 rpm shaft speed. The propellant pressure was 85 psig. This seal was run through two test cycles with a total accumulated run time of 73 minutes and 20 seconds. The following leakage rates were recorded:

Run No.	Run Time Seconds	Prerun Static Leakage cc/min	Dynamic Leakage cc/min	Postrun Static Leakage cc/min
545	60			
546	120	0	2	0
547	180	0	0.5	0
548	240	0	0.3	0
549	400	0	0	0
550	400	0	0	0
551	400	0	0	0
552	400	0	0	0
553	60	0	0	0
554	120	0	0	0
555	180	0	0	0
556	240	0	0	0
557	400	0	0	0
558	400	0	0	0
559	400	0	0	0
560	400	0	0	0

Postrun inspection showed the seal to be in good condition. The arbon nose piece was worn approximately 0.015 inch, but displayed a good even wear pattern. The   tting ring displayed superficial check marks on the wear surface.

(5)   The fifth seal configuration evaluated was Sealol Seal No. A-   9 (2.126-inch OD and 1.410-inch ID), a bellows type face seal with antirotation locks. This se   onsisted of a G-39 Graphitar carbon face, 0.006-inch thick, type 410 stainless steel bellows, and   · series stainless cup and end pieces (Figure 84, photograph taken after test). The mating rin   s chromium carbide flame plated No. B-16341 (Figure 85, photograph taken after test). The seal fa   ·b'

velocity was 105 ft/sec at 14,000 rpm shaft speed. The propellant pressure was 85 psig. The seal was tested through two test cycles accumulating 73 minutes and 20 seconds run time. The following leakage rates were recorded:

Run No.	Run Time Seconds	Prerun Static Leakage cc/min	Dynamic Leakage cc/min	Postrun Static Leakage cc/min
561	60	0	5	0
562	120	0	1	0
563	180	0	1	0
564	240	0	0	0
565	400	0	1	0
566	400	0	0.5	0
567	400	0	0	0
568	400	0	0	0
569	60	0	0	0
570	120	0	0	0
571	180	0	0	0
572	240	0	0	0
573	400	0	0	0
574	400	0	0	0
575	400	0	0	0
576	400	0	0	0

Postrun inspection showed the seal to be in good condition. The carbon nose piece was worn approximately 0.010 inch, but showed a very smooth wear pattern. The chromium carbide flame plated seal face on the mating ring showed a very smooth wear pattern with very slight indication of scuffing or check marks. This is an improvement over the last test when this type seal configuration was evaluated with a 316 stainless steel mating surface where the check marks or scuffing was more severe.

(6)   The sixth seal configuration evaluated was a Sealol Seal No. A-25094 (2.126-inch OD and 1.410-inch ID) bellows type seal. This seal consisted of a glass impregnated Teflon seal face, with a 0.005-inch thick AM-350 stainless steel bellows and 300 series stainless steel cup and end pieces (Figure 86, photograph taken after test). The mating ring was 316 stainless steel (Figure 87, photograph taken after test). The seal face rubbing velocity was 105 ft/sec at 14,000 rpm

shaft speed. The propellant pressure was 85 psig. The seal was evaluated through two test cycles, with a total accumulated run time of 73 minutes and 20 seconds. The following leakage rates were recorded:

Run No.	Run Time Seconds	Prerun Static Leakage cc/min	Dynamic Leakage cc/min	Postrun Static Leakage cc/min
577	60	0	0	0
578	120	0	0.5	0
579	180	0	5	5
580	240	5	9	25
581	400	25	4	4
582	400	4	1	15
583	400	15	0	10
584	400	10	2	10
585	58	6	6	4
586	120	4	1	6
587	180	6	4	2
588	240	2	5	4
589	400	4	7	2
590	400	2	1	0
591	400	0	0	0
592	400	0	0	0

During postrun inspection, the glass impregnated Teflon face displayed a smooth wear pattern with some grooving. The face wore approximately 0.015-inch. The 316 stainless steel mating ring also displayed a good wear pattern with some minute circumferential grooving less than 0.001-inch in depth.

(7)   The seventh seal configuration evaluated was Sealol Seal No. A-9152 (2.188-inch OD and 1.468-inch ID), a packing type face seal. This seal consisted of a glass impregnated Teflon face and Teflon internal static seal packing with 300 series stainless steel skirt and cup (Figure 88, photograph taken after test). The mating ring was 316 stainless steel (Figure 89, photograph taken after test). The seal face rubbing velocity was 103 ft/sec at 14,000 rpm shaft speed. The propellant pressure was 85 psig. The seal was tested for 73 minutes and 20 seconds. The following leakage rates were recorded:

Run No.	Run Time Seconds	Prerun Static Leakage cc/min	Dynamic Leakage cc/min	Postrun Static Leakage cc/min
593	60	0	2	0
594	120	0	5	8
595	180	8	17	8
596	240	8	4	8
597	400	0	64	70
598	400	70	23	25
599	400	25	11	50
600	400	50	38	175
601	60	175	60	100
602	120	100	55	90
603	180	90	33	75
604	240	75	19	75
605	400	5	5	10
606	400	10	11	50
607	400	50	32	35
608	400	35	8	35

Postrun inspection showed that one of the wave springs was jammed over the spring separator washer, thus preventing proper spring action in the seal and preventing proper seal face contact which resulted in high leakage rates. The sealing faces showed excellent wear patterns.

(8)   The eighth seal configuration evaluated was Sealol Seal No. A-19936 (2.424-inch OD and 1.530-inch ID), a bellows type face seal. The seal consisted of a glass impregnated Teflon face with 347 stainless steel bellows (Figure 90, photograph taken after test). The mating ring was 316 stainless steel (Figure 91, photograph taken after test). The seal face rubbing velocity was 109 ft/sec at 14,000 rpm shaft speed. This seal was tested for 39 minutes and 19 seconds at which time testing was terminated due to excessive leakage. The following leakage rates were recorded:

Run No.	Run Time Seconds	Prerun Static Leakage cc/min	Dynamic Leakage cc/min	Postrun Static Leakage cc/min
609	60	0	10	0
610	120	0	28	0
611	180	0	47	10
612	240	10	38	10
613	400	10	6	140
614	400	140	10	175
615	400	175	8	175
616	100	350	186	350

Postrun inspection showed that the bellows took a permanent set at the operating seal height, thus preventing proper seal face contact and causing high static and dynamic leakage. This type of permanent setting occurs occasionally with type 347 stainless steel bellows since this material is not heat-treatable. The sealing faces were in good condition with no visible wear.

(9)   The first bearing evaluated in liquid N_2O_4 was an MRC205-S stainless steel ball bearing (Figure 92, photograph taken after test), manufactured by Marlin-Rockwell Corporation. The inner race, outer race, and balls are 440C stainless steel and the bearing cage is machined and riveted "S" monel. In conjunction with the ball bearing evaluation, the Sealol Seal No. MFC-20JOB-22, with a 316 stainless steel mating ring, was further tested. This seal had been previously tested for a total of 81 minutes. The seal consists of an AM-350 stainless steel bellows, cups, and end pieces and the seal face insert is Graphitar G-39 carbon (Figures 93 and 94, photographs taken after test). The seal face rubbing velocity was 105 ft/sec at 14,000 rpm shaft speed. The propellant pressure was 85 psig. A total running time of 45.5 minutes has been accumulated on the bearing and 126.5 minutes on the seal. The bearing was inspected and no detrimental effects noted. The seal and sealing faces were in excellent condition. The bearing was evaluated under the following load conditions:

Run No.	Run Time Seconds	Radial Load Lb	Thrust Load Lb	Dynamic Seal Leakage cc/min
617	60	0	0	0
618	60	34	19	0
619	60	62	34	0
620	60	102	51	0
621	60	152	75	0
622	60	201	98	0
623	454	200	100	0
624	1200	200	100	0
625	720	200	100	0

See Figures 95 and 96 for plots of temperature versus time for test ball bearing for Runs 617 through 625. Figure 97 is a plot of ball bearing temperature rise versus applied radial and thrust load in pounds for the test ball bearing which is completely submerged in N_2O_4. It is noted from the plot, that when the applied radial and thrust loads increase, the ΔT (bearing temperature rise) decreases.

(10)   The second bearing configuration evaluated in liquid N_2O_4 was a sleeve-type bearing. The bearing material is glass impregnated Teflon. Figure 98 is a photograph of the sleeve bearing after test, and Figure 99 is a photograph of the sleeve bearing shaft after test. In conjunction with this test, Sealol Seal No. A-19169 was further evaluated with a 316 stainless steel mating ring. The seal face rubbing velocity was 105 ft/sec at 14,000 rpm shaft speed. The propellant pressures were 85 and 130 psig. The bearing was evaluated under the following load conditions:

Run No.	Run Time Seconds	Radial Load Lb	Dynamic Seal Leakage cc/min
627	60	0	0
628	60	30	0
629	60	60	0
630	51	100	0
631	53	100	0
632	60	100	0
633	80	166	0
634	61	166	0

This bearing test was stopped after Run 634 due to the clogging of the bleed orifice. Total time accumulated on the bearing was 8 minutes and 5 seconds.

Postrun inspection of the sleeve bearing indicated heavy wear in the direction of the applied radial load, indicating poor load carrying capability for this material. Figure 100 is a plot of bearing temperature versus running time in seconds for the sleeve-type test bearing at various applied radial loads and propellant bleed orifices. For Runs 630 through 634 inclusive, the bleed orifice was plugged by Teflon particles which originated from the test bearing.

(11)   The third bearing configuration evaluated was an MRC-205C1, Class 5 roller bearing (Figures 101 and 102, photographs of bearing taken after test). This bearing consisted of SAE 52 100 steel rollers, and outer and inner races with a bronze cage separator. A new Sealol Seal No. A-19870 (2.126-inch OD and 1.410-inch ID) was evaluated in conjunction with the bearing test. The seal is a bellows type face seal having Inconel X Bellows and a Purebon Carbon 658 RC seal face insert (Figure 103, photograph of test seal taken after test). The mating ring was 316 stainless steel (Figure 104, photograph taken after test). A total time of 80 minutes and 51 seconds was accumulated on both the test bearing and the seal. The seal face rubbing velocity was 105 ft/sec at 14,000 rpm shaft speed at the following bearing loads. The propellant pressure was 130 psig.

Run No.	Run Time Seconds	Radial Load Lb	Dynamic Seal Leakage cc/min
635	331	166	0.9
636	340	166	0.9
637	399	166	4.5
638	467	166	1.3
639	65	166	0.5
640	405	166	2.2
641	320	166	0.9
642	360	166	7.5
643	1380	166	1.1
644	457	200	1.97
645	327	200	0

Postrun inspection showed the bearing to be in good condition with discoloration noted on the inner and outer races. The 316 stainless steel mating ring displayed a good even wear pattern with light superficial scuff marks. The Purebon Carbon 658 RC seal face insert displayed a very smooth wear pattern. The Inconel X bellows showed no sign of chemical attack from the test fluid. Both the bearing and the seal are in good condition for future evaluation. Figures 105 and 106 are plots of bearing temperature versus running time in minutes for the test bearing at various applied radial loads and two propellant bleed orifices, 0.025- and 0.040-inch diameter. These figures indicate that the maximum bearing temperature rise was approximately 18 F whenever the bleed orifice was not plugged. This plugging was traced to the butyl rubber O-rings used on the radial load piston which were attacked by the N_2O_4. It was found that the butyl rubber O-rings gave trouble free service when exposed to liquid N_2O_4 for approximately an eight-hour period.

(12)   The fourth bearing configuration evaluated was a sleeve-type bearing identical to the previous sleeve-type bearing tested except that the bearing material was graphite impregnated Teflon (Figure 107, photograph of sleeve bearing taken after test, and Figure 108, photograph of sleeve bearing shaft taken after test). In conjunction with this test, Sealol Seal No. A-19169 was further evaluated with a 316 stainless steel mating ring (Figures 109 and 110, photographs of test seal and mating ring, respectively, taken after test). The seal face rubbing velocity was 105 ft/sec at 14,000 rpm shaft speed and the propellant pressure was 130 psig. The bearing was evaluated under the following load conditions for 9 minutes and 43 seconds:

Run No.	Run Time Seconds	Radial Load Lb	Dynamic Seal Leakage cc/min
646	103	200	0
647	75	200	0
648	405	200	0

Postrun inspection of the sleeve bearing indicated heavy wear in the direction of the applied radial load, indicating poor load carrying capability for this material as previously experienced with the glass impregnated Teflon sieeve bearing. Figure 111 is a plot of bearing temperature versus running time in minutes. Runs 646 and 647 were halted when the propellant temperature reached 163 F. For both runs, the bleed orifice was plugged by Teflon particles. Run 648 was terminated when the propellant supply to the test rig was emptied. For this run, the bearing temperature rise was 33 F in 6 minutes and 45 seconds.

The total time accumulated on test seal A-19169 is two hours, 44 minutes, and 28 seconds. Both the carbon seal insert and the stainless steel mating ring displayed excellent wear patterns. The seal hardware in general is in excellent condition for future tests.

b.   Pump Tests

As the propellants under study are liquids under normal conditions of temperature and pressure accompanied with normal viscosities, it can be stated that each will respond to the classical equations for determining pump design and performance. Therefore, when due consideration is given to the materials of construction, no difficulty should be encountered in a pump-fed, storable-liquid rocket engine.

To date, Bell Aerosystems has accumulated approximately 28 months experience in pumping UDMH in the development of the WS-117L (Bell Agena) second-stage rocket engine. Both

aluminum and magnesium are being used for pump housings, and aluminum for pump impellers, with no detrimental compatibility problems. This particular pump delivers 140 gpm at 850 psia with a rotative speed of 24,570 rpm at an inlet head of 100 feet.

In general, the pump efficiency is a function of the pump specific speed N_s, given in the equation

$$N_s = NQ^{0.5}/H^{0.75}$$

where:
- N = Rotative speed in rpm
- Q = Impeller through-flow in gpm
- H = Impeller head rise in feet

Thus, for a given system requirement of flow and head, the higher the rotative speed, the smaller the impeller (as head is proportional to the square of the product of speed times diameter), and the lighter the pump, the higher the specific speed and efficiency.

Coupled with the obvious advantage of high rotative speed pumps, is the consideration of the pump inlet pressure requirement. The suction specific speed (S), defined below, becomes the primary factor limiting the maximum rotating speed as low pump inlet pressures are also desirable for missile systems.

$$S = NQ^{0.5}/H_{sv}^{0.75}$$

where: N and Q are as previously defined

H_{sv} is total pump inlet head above fluid vapor pressure in feet. Hence, for a given system flow and pump inlet pressure, the highest attainable suction specific speed will permit the highest rotative speed.

Because of the rather high vapor pressure of N_2O_4, and the desirability to keep pump inlet pressures as low as possible, the primary emphasis during the literature search was on pump inducers. By definition, an inducer is an axial flow pump that is deliberately designed to accommodate some cavitation at the inlet. It is not capable of high head generation. However, it is ideally suited as an intermediate device between the tank and main stage centrifugal pump to permit a lower system tank pressure without compromising the high speed main stage pump.

From Reference 91, the following important conclusions can be made:

(1) Design suction specific speeds of 35,000 for single suction pumps and 50,000 for double suction pumps are attainable with inducers, whereas 15,000 is maximum for conventional centrifugal pumps

(2) Cavitation performance improved for the following geometry changes:

(a) For a constant solidity, a decrease in turning angle and an increase in the flow coefficient

(b) Increased solidity; however, for high solidity inducers, the best performance was obtained at low-flow-coefficients

(c) With smoother blade surfaces at high fluid velocities

(d) By eliminating the rotating shroud around the inducer outside diameter – gave a significant improvement over the shrouded inducer

      (e)   By using a conical shaped inducer, i.e., the inlet diameter larger than the outlet diameter – gave a significant improvement over a constant diameter inducer

      (f)   By using a generous radius or sweep at blade inlet – gave a significant improvement over a straight radial blade inlet

   (3)   The cavitation performance of the combined inducer – main stage pump was substantially improved by removal of stationary guide vanes between them

   (4)   An increase in solidity produces:

      (a)   A decrease in maximum efficiency

      (b)   An increase in cavitation performance

      (c)   A decrease in the ratio of optimum flow rate to the maximum flow rate

   (5)   The cavitation performance was substantially better with liquified gases than with water

At this point, the definitions of some of the preceding terms will help to clarify the statements.

      Solidity is a dimensionless ratio of the inducer blade chord length to the peripheral pitch between blades. The blade development on a cylinder of revolution whose diameter is the root mean square diameter between hub and tip is generally used for the characteristic solidity.

      Turning angle is the difference between the blade direction at discharge and inlet.

      Flow coefficient is the tangent of the inlet angle with respect to the plane of rotation or more precisely the ratio of the axial fluid velocity at inlet to the peripheral blade velocity. This coefficient is generally described at the root mean square diameter.

      Ross and Benerian, in Reference 84, discuss some of the aspects of high suction specific speed inducers. A general equation is developed relating the suction specific speed to the inlet geometry and energy conditions. This equation is next differentiated to obtain optimum inlet diameter and the maximum suction specific speed. Other information is given on the basis of test information as follows:

   (1)   Inlet angles up to 2 greater than that required for shockless entry are necessary at the optimum inlet diameter for best cavitation performance – suspect prerotation.

   (2)   The suction specific speeds for well designed inducers are not limited to that corresponding to incipient cavitation since well designed inducers gradually recompress the vapor.

   (3)   The head generation decreases as the suction specific speed increases for a fixed flow coefficient because of more and more of the vane being required to recompress the vapor leaving less for head generation.

   (4)   A large inlet area which decreases towards the discharge is required to get good cavitation characteristics. This results from continuity considerations where lower density double phase fluid exists at the inlet.

(5)   The efficiencies of the long bladed inducers are lower than would be expected of pumps having comparable specific speeds. Test indicate the efficiency ranges from 40% to 65%.

(6)   To offset (5), the longer blade inducer makes possible higher suction specific speed operation and considerably less cavitation damage than the shorter blade inducer having the same solidity.

Stahl and Stepanoff developed, in Reference 85, an expression relating the thermodynamic properties of a fluid to the fluid's ability to change phase and occupy space. An adiabatic process is assumed where the heat of vaporization must come from the liquid surrounding the low static pressure zone in the pump where cavitation pockets form. This in turn causes the fluid temperature to drop. The expression is

$$B = \frac{V_v}{V_1} \cdot \frac{v_v}{v_1} \cdot \frac{\Delta h_1}{L}$$

where: V   represents volume

         v   Specific volume at saturation temperature

         Δh enthalpy change due to the temperature change of a saturated fluid for a prescribed change in equilibrium pressure between liquid and gas phases.

         L   latent heat of vaporization and subscripts 1 and v refer to liquid and vapor respectively.

         B   dimensionless ratio.

The value B may be calculated for various fluids by assuming the same small change in vapor pressure and a comparative estimate obtained for the cavitation performance of the fluids in a given pump. The smaller B, the better the cavitation performance. Reference 85 tabulates this factor for water at different temperatures for a vapor pressure depression of 1.6 inches. This tabulation and additional calculated values for liquefied gases and N_2O_4 appear in Table 78. The UDMH is not computed since the specific volume of saturated vapor is not known.

In summarizing their findings, the following is stated:

(1)   Cavitation effects when pumping various liquids are similar for dynamically similar conditions if the thermal cavitation criteria B calculated for the same equilibrium pressure depression, are equal.

(2)   Owing to the thermal and dynamic limitations only a small fraction of one percent by weight of the liquid is vaporized under cavitation conditions.

(3)   Under incipient cavitation conditions, extension of test data to other conditions or to other sizes of units by the dynamic similarity requirements of $\sum H_{sv}/H$ constant, is approximate. Thus, a given pump operated at various speeds will require less H_{sv} at higher speeds than indicated by extension of test data taken at lower speeds since the amount of boiling liquid is limited by the lapsed time the liquid stays in the cavitation zone.

(4)   The absolute value of the cavitation thermal criterion B is not important as long as it is used for a comparison of pump behavior under cavitation conditions when handling liquids of different physical properties.

(1)   Pumping UDMH

Pump test data was obtained from experience obtained in pumping UDMH in the development of the WS-117L (Bell Agena) second-stage rocket engine. The sealing arrangement on the UDMH pump which has been used effectively consists of a primary face type pressure balanced seal rubbing on a rotating sealing ring. This seal is backed by a lip type shaft seal which functions as a barrier between the UDMH fluid leakage past the primary seal and the lube oil contained in the gear box. Any UDMH leakage past the primary seal is drained overboard from the cavity between the primary seal and shaft seal. Specification requirements limit the primary face seal leakage to 200 cubic centimeters in four minutes at operating temperatures (32° F to -90° F).

The current primary seal configuration is a Sealol Corporation bellows seal. The bellows is the leaf type of welded construction using AM-350 steel. The sealing face insert is carbon Graphitar G-39 and the mating rotating sealing ring is type 316 stainless steel. The shaft lip type seal consists of a type 302 stainless steel housing; the sealing lip element is butyl rubber.

Glass filled Teflon has also been used successfully as a seal face material in conjunction with a type 316 stainless steel mating sealing face and as the sealing element in the shaft lip type seal.

Another face type seal configuration which was used extensively in the first UDMH pump configuration, was a standard pressure balanced face seal, manufactured by Sealol Corporation. This type seal consists of a seal ring which is keyed to the stationary housing and contacts a mating seal surface which is constrained to rotate with the shaft. The two sealing surfaces are 316 stainless steel for the mating ring, and Graphitar G-39 for the seal ring. Secondary sealing takes place between the seal ring skirt and stationary seal housing by means of V-type butyl rubber packing.

Butyl rubber O-rings and virgin Teflon gaskets have been effective static seals for both high and low pressures.

Figure 112 is a photograph of a fuel pump impeller that has accumulated four hours operation in UDMH. During this time, operation was at approximately 25,000 rpm, flow of 150 gpm, suction specific speed of 15,000 (gpm units), and a cavitation index of 10. The anodized finish on the aluminum inducer being undisturbed after this time is evidence of the lack of cavitation damage. The cavitation zone is at the outside diameter of the inducer inlet. The lack of cavitation damage is due to the low pressure in the region of vapor recompression, and the modest cavitation index.

Figure 113 is a plot of the cavitation characteristic of a fuel pump having a similar impeller to that of Figure 112. The tests were conducted with UDMH. The figure contains two curves. One shows the effect at constant speed of the inlet head above vapor pressure on the pump flow, while the other indicates the suction specific speed of the pump.

(2)   Pumping N_2O_4

The test conducted during this program involved the Model 8096 oxidizer pump hardware, N_2O_4 and water as test liquids, and helium and nitrogen as pressurization gases. The pump seal was a bellows type having a Graphitar G-39 nose piece rubbing against a flat stainless steel rotating ring. A total of 12 cavitation tests were made in the program. Table 79 contains the test log for this program.

The tests were conducted in a recirculating system, i.e. the fluid was taken from the supply tank through a screen filter and valve to the pump suction, pumped, and then returned to the same tank through two flowmeters and a pump back pressure control valve. Appropriate pres-

sure and temperature measurement points were added. The total volume of the system was approximately 300 gallons, 200 gallons of which was liquid. The pumped flowrates were approximately 150 gpm which means complete fluid turnover in 80 seconds. This system volume is approximately 1/2 to 1/3 the size normally used but was compromised on the basis of available tankage. Other than the system volume, the line (supply and return) configuration was standard. Liquid was taken from the tank bottom and returned through a diffusion tube. The diffusion tube discharged the fluid into the tank under the liquid level at the top of the tank, and parallel to this level.

The tests were conducted by holding speed constant at 12,200 rpm and adjusting the pump discharge pressure to a value equal to or less than pump case pressure. The pump suction pressure was then varied and the effect on pump flow measured. The test data thus obtained was corrected to a common speed of 12,200 rpm by similarity laws, and the suction specific speed calculated. This method of conducting a cavitation test departs from that used for the common pump configuration because of the unique characteristic of the Bell pump where pump back pressure less than case pressure does not affect the flow.

The tests listed in the test log were conducted in groups as follows:

Group 1 includes runs 1942 and 1943. Run 1942 was made with N_2O_4 as the pumped fluid, nitrogen gas pressurization, and with no inducer. Run 1943 was made with an inducer similar to the one in Figure 112. Difficulty was encountered with these tests. The data indicated premature cavitation and an excessive buildup of pump back pressure as the run progressed. It was also noted that the first data point (Figure 114), at the start of run 1943, was satisfactory. This point was never realized later in the run when the high suction pressure was increased then reduced in steps. "Breakdown" occurred at 55 feet of pump inlet head. As a result, the N_2O_4 was analyzed for purity and was found to meet specification. Solubility of nitrogen in N_2O_4 was questioned since it was suspected that soluble gas was being liberated in the low pressure regions of the pump inducer causing premature "breakdown". No data was available; therefore, a test was made in the laboratory. The results are reported elsewhere in this report. No explanation for the increase in back pressure could be made. In addition, the recirculation system was reinspected to insure proper configuration. All succeeding pump runs were made with an inducer.

Group 2 consists of runs 1944 and 1945. Run 1944 was made to repeat run 1943, but with back pressure controlled. Premature cavitation was again obtained at 55 feet pump inlet head. Run 1945 was then made with water to determine if acceptable performance could be obtained in the recirculating system. The performance was normal as shown in Figure 114.

During the succeeding investigation, it was found that the Kel-F bushings in the Potter flowmeters were swelling in the liquid N_2O_4. This could bind the flowmeter as fluid was pumped through and obviously affect the sensitivity. This also explains the buildup of back pressure on the pump. The two flowmeters were modified with Graphitar G-39 bushings, and no trouble was observed on the following tests; also, the solubility of helium and nitrogen was determined in the laboratory. Helium was found less soluble.

Group 3 tests consisted of runs 1946 through 1953. The purpose of these tests was to determine the effect of helium and nitrogen gas pressurization on the N_2O_4 cavitation performance. Fresh N_2O_4 was loaded and maintained under a helium blanket and changed to nitrogen after a successful test with helium. Only runs 1950 and 1953 produced useful data. The other runs were not useful due to premature shutdown because of leaks, or instrumentation failures. The data for these runs are plotted in Figure 114.

Figure 114 also shows the useful data obtained from this program. Two curves are presented. The upper one shows pump suction specific speed versus pump inlet head

above vapor pressure. The lower one is a plot of the pump cavitation flow factor versus inlet head. The cavitation flow factor is the ratio of the test flows for all tests to the test flow obtained from the water test at the design rated pump inlet head of 25 feet. The flow differences in the high head regions are not significant. The significance lies in the slope changes of the curves and the point of flow "breakdown".

N_2O_4 was not pumped to the same degree of cavitation performance as water. Cavitation "breakdown" occurred at 5 feet with water (44,000 suction specific speed) and at 20 feet with N_2O_4 and helium pressurization (16,000 suction specific speed).

N_2O_4 cavitation performance was considerably better using helium gas for pressurization than with nitrogen gas. This indicates that the dissolved pressurization gases may have an adverse effect since, on a mole basis, helium is less soluble than nitrogen. On the other hand, one point at the start of run 1943 (using N_2 gas) showed as good performance as run 1950 (using He gas), indicating another influence.

The effect of the small system volume is not known, but a detrimental effect is a strong possibility. The temperature rise of approximately 2 F/min is indicative of inadequate system volume.

No data was obtained on pump cavitation performance in N_2O_4 with and without an inducer due to problems encountered in Group 1 tests.

No difficulty was encountered with the pump seal. Static leakage were nil and dynamic leakages were very low.

5.   Propellant Storage

A search of the technical literature revealed a great deal of information on long-term storage of N_2O_4, UDMH, and N_2H_4 at ambient temperature. Of prime interest is the fact that the fuel vendors recommend storing each fuel under a nitrogen blanket.

T. J. McGonigle (References 32 and 55) reports that N_2O_4 was stored in a small carbon steel container for nine years at ambient temperature (68 - 100 F). Analysis showed no change in composition. Actual analysis was 99.8 N_2O_4, 0.002 chloride, 0.16 water equivalent, and 0.004 ash. This was a pilot plant product and contained about 0.02 water equivalent when made.

According to one vendor (Reference 86), UDMH was stored in mild-steel, 55-gallon drums, and in a Nike-Ajax aluminum container at ambient temperature. Temperature and pressure were monitored over a period ranging from 16.5 to 20.5 months. During this period, little pressure build-up was noted. The temperature range over the storage period was 47 to 86 F. Analysis before and after test indicated little or no change. Tables giving temperature and pressure during the storage period can be found in Reference 86 along with photographs of drums during test and after. Jet Propulsion Laboratory (Reference 87) also demonstrated that there was no pressure buildup when UDMH was stored for four weeks at 160 F, whereas certain other hydrazines did not pass this test. Recently, Food Machinery and Chemical Corporation stored UDMH outdoor three mild-steel drums for 38 to 41 months. Analysis of the UDMH at the end of these peri   met all specifications (Reference 90).

G. L. Choules (Reference 65) reports that anhydrous N_2H_4 wh   was produced for Redstone Arsenal in 1953-54, was stored outdoors until 1957 when it was   ed to the Missile Development Division of North American Aviation. It was later transferre   Rocketdyne. A comparison of the propellant analysis performed at each of the three facilities in   d practically no change (approximately 97%). Periodic checks for pressure buildup, which would be indicative of

decomposition, were also carried out at Redstone with negative results. Choules also states that the Naval Ordnance Test Station at China Lake has stored N_2H_4 for several years without any decomposition, even at the high-storage temperature encountered in the area. In both of these instances, the N_2H_4 was stored in aluminum (99.6%) and stainless steel drums.

Although considerable information on storage was found, this information, referenced above, did not give all the data required. It was planned, therefore, to conduct a three-month storage test in sealed tanks of ten-gallon capacity with each propellant held at a constant temperature near its boiling point, and a six-month storage test in sealed tanks of ten-gallon capacity, left outdoors where temperature fluctuations occur daily and with change of season. For the three-month storage test, the propellants were analyzed before and after the test, and for the six-month storage test the propellants were analyzed before the test, periodically during the test, and after the test.

The tanks used for each test were equipped with pressure gages which were monitored regularly as an alternate means for detecting propellant decomposition.

Six 6061-T6 aluminum, and six PH 15-7 Mo stainless steel, ten-gallon capacity tanks were obtained for these tests. The aluminum tanks were cleaned, pickled in accordance with Reference 61, and visually inspected. The stainless steel tanks contained unexpected heavy scale deposits which necessitated special handling. They were first degreased, then pickled in a nitric acid-hydrofluoric acid solution, rinsed with cold water, pickled in a sodium hydroxide-potassium permanganate solution, again rinsed with cold water, dipped again in the acid pickling solution, and finally rinsed with cold and hot water. The tanks were hydrotested in accordance with MIL-T-5208A (Reference 88) to 300 psi. Having been found acceptable, the PH 15-7 Mo stainless steel tanks were spray-painted on the external surface to prevent corrosion. All twelve tanks were conditioned and fitted with valves, gauges, and other necessary hardware.

Storage tests at temperatures near the boiling point of UDMH, N_2H_4, and N_2O_4 were conducted for a three-month period using the aforementioned tanks. One of each alloy was used for each propellant. The tanks were filled, according to a procedure which is described under a later section on outdoor temperature storage test, and set in appropriate constant temperature baths. The fuels were put in an oven set at 160 F and the oxidizer in a building maintained at 70 ± 10 F. In addition, the oxidizer tanks were fitted with strip heaters to be used if necessary. Periodic pressure readings were taken from gages so situated that the fuel oven was not opened, nor the oxidizer building entered. The tank set-ups are shown in Figures 115 and 116. Pressure data gathered are given in Tables 80 and 81. Analyses of the propellants at the start and at the end of test are shown in Tables 82 and 83. Originally, it was intended to add to the latter tables only the analyses at the end of tests. Because seal leaks caused interruption of the fuel tests, Table 82 also contains analytical data obtained on the 28th day to be certain that the fuels had not changed composition.

In general, pressure buildup in the 160 F fuel storage test was slightly higher in the PH 15-7 Mo stainless steel tanks than in the 6061-T6 aluminum tanks. However, only the PH 15-7 Mo stainless steel tank of UDMH rose to the pressures anticipated. Analyses at the end of the test indicated that little or no change in composition had occurred in the propellant. Visual examination of the interior of each tank after test indicated no corrosive attack. These results and observations show that under the conditions tested, UDMH and N_2H_4 are stable and that no special preference for tank material can be made.

A close inspection of temperature-pressure records for the oxidizer tests at 70 F show a lag at times, presumably due to the fact that the thermocouples picked up the temperature changes before the N_2O_4/NO_2 equilibrium adjusted to a different vapor pressure. No significant pressure buildup was noted throughout the test period. In fact, pressures generally were less than calculated with somewhat closer agreement with the steel tank than with the aluminum. No change in composi-

tion was noted from analysis at the end of the test. A visual examination of the interior of each tank revealed no deposits or signs of an attack on the metal.

Outdoor temperature storage tests with UDMH, N_2H_4, and N_2O_4 were conducted for a period of six months using ten-gallon, PH 15-7 Mo stainless steel and 6061-T6 aluminum tanks. They were filled by the procedure described in the following paragraphs.

Each tank contained two ports. To one of these was attached a cross fitting to which in turn were attached a pressure gage, a burst disc assembly, and a bleed valve. To the other was attached a hand valve and, for tanks to be used with N_2O_4, a standpipe. All tanks were subjected to 20 psig pressure after conditioning. The tanks were placed, one after another, on a platform scale and connected to a shipping container of propellant by means of the hand valve, and to a vent line with the bleed valve. The fuels were transferred from drums, the oxidizer from cylinders. Nitrogen pressure was applied to the drums (the cylinders were under sufficient pressure as received), the valves opened, and propellant allowed to flow into the tank until a weight sufficient to give a predetermined ullage was attained. The valves were then shut off, the lines disconnected, and the tanks set outside on storage racks. The fuel tanks are shown in Figure 117, the oxidizer tanks in Figure 118.

Pressure readings were taken on the average of once a day during the work week, and liquid and vapor samples were taken periodically, using the following procedures.

Nitrogen pressure was applied to the bleed valves on the oxidizer tanks, forcing liquid up through the stand pipe, through the hand valve, and into a glass bottle in a dry-ice bath. Because the fuel tanks had no standpipe, liquid samples were obtained by pressurizing the tanks slightly with nitrogen by means of the bleed valve, tipping the tank after disconnecting the pressurizing line, and allowing the fuel to flow into a glass bottle from the bleed valve. Vapor samples were obtained by attaching an evacuated glass balloon to the bleed valve and opening the valve.

Pressure readings are shown in Tables 84 and 85. In addition, these tables show start dates, initial ullages, prevailing temperatures, and sampling periods. Chemical analyses of the liquid samples at the start and the end of test are shown in Tables 86 and 87. Because of the transfers involved and the requirement to store at one site and analyze at another, accuracy necessarily suffers but not to the point where significant changes would escape notice. Besides being subjected to chemical analysis, the liquid samples were tested for impact sensitivity. Vapor samples were merely subjected to infrared analyses. The results of these analyses and the other data collected is reviewed in the following.

Pressure records gathered during the six-month fuel storage test at outdoor temperatures showed no significant buildup. In general, there is a good correlation between temperature and pressure, and the pressure for UDMH appears to stem from compression of the nitrogen originally present during thermal expansion of the fuel, and the vapor pressure of the fuel. Corresponding data for N_2H_4 was somewhat higher but not enough to postulate decomposition. These conclusions are substantiated by the fact that chemical analysis of the liquid samples on the 18th, 52nd, 84th, and 102nd days showed no change in composition, and there was no evidence of impact sensitivity. No attack of the metal was noted when the interior of each tank was examined.

In the same way, pressure records gathered during the six-month oxidizer storage test at outdoor temperatures showed no significant buildup or difference between the two tank materials so far as pressure buildup was concerned. Propellant analysis on the 45th, 75th, and 94th days showed no significant change. Stability is further indicated by the fact that chemical composition

was not changed nor was impact sensitivity increased. Further definition of the impact sensitivity tests will be given after a discussion of vapor sample analyses. Examination of the interior of each tank revealed no attack of the metal.

As mentioned previously, samples were taken starting with evacuated glass balloons. Originally, 1000-ml (approximately 1 qt) or 500-ml (approximately 1 pt) balloons were used. Experience has shown that a smaller sample would suffice and consequently, 200-ml balloons were ordered. The samples are transferred to gas cells using a simple gas handling train assembled from standard gas analysis manifolds with ball and socket joints, a vacuum pump, cold traps, a mercury manometer, and an "auto-bubbler" containing Kel-F-3 oil to keep propellant vapors from reaching the mercury. A photograph of the train is shown in Figure 119. The gas cells have a 10-cm (4-in.) light path. The cell for fuel analysis has been fitted with sodium chloride windows, and the one for N_2O_4 with silver chloride. Both are mounted in the compartment provided in a Beckman IR-2A Spectrophotometer.

The spectra obtained were compared with those published in Reference 89. A consistent exception is a set of peaks due to a hydrocarbon found in the N_2H_4 spectra. This is as would be expected in view of the manufacturing procedure used. Samples analyzed at the end of the tests also contained traces of ammonia, suggesting some decomposition occurred in the vapor phase. The first set of N_2O_4 samples showed free nitric acid but this was absent in subsequent samples. It was concluded that moisture was inadvertently picked up with the first samples.

As mentioned previously, impact sensitivity tests of the propellants were performed on the propellant as received. A minimum of 10 tries with each propellant showed lack of sensitivity up to seven ft-lb, the limit of the apparatus (Figure 120). Samples taken during and after the storage tests for both fuel and oxidizer showed no increase in shock sensitivity.

6.   System Analysis

a.   System Flow Tests

A storable propellant flow system was built up per the schematic drawing (Figure 58). This system was set up to simulate a typical rocket engine system including valves and piping, but without thrust chambers, gas generator, or turbine pump. The valves used in this system are listed in Table 88 with a brief description of the modification required to adapt them for this program. The system incorporated all the necessary instrumentation and test equipment to record pressures and flows. Figure 136 shows a mock up of the valves and hardware mounted on a bench. Figure 137 shows the high pressure and low pressure tanks with piping on the fuel side of the test facility.

The respective propellants were supplied at a high pressure from pressurized storage tanks through the selected valves and components, which were actuated to simulate functioning in the engine system. The respective propellants were then returned to the receiver tanks, which were modified Rascal propellant tanks.

After a selected amount of cycles, the propellants were transferred back to the storage tanks to start another series of cycles. The low pressure supplied by the Rascal regulator pack was used to transfer the propellants.

Data recorded included supply tank pressure, flow, and pressure drops at a flow rate ranging from rated to 30% of rated. An average of 5 points was recorded and plotted for each flow test. Using recorded flow data, curves were plotted for an equivalent flow of water to simplify the conversion of the flows to any other liquid propellant (Figures 59 through 68).

The systems were subjected to flow tests at room temperature $(70 \pm 10°F)$ and at elevated temperature $(160 \pm 5°F)$. Following the elevated temperature cycles, a series of final room temperature cycles were conducted at the same flow rates to compare results with the initial room temperature data.

Tables 65 through 72 show these data and conclusions for each valve tested, and Figures 138 through 155 show photographs of each disassembled valve after flow tests.

Data for other valves in the storable propellant flow system which saw exposure to the propellants but did not have flow data recorded, are described in the following paragraphs.

(1)   Valves used for both UDMH and N_2O_4 service

(a)   Valve-Dual 2-Way Motor Operated, Ball type (P/N 83 B/P 200834)

This valve was used in the system as a fuel and oxidizer pressure jettison valve (Figure 123). The original manufacturer of this valve (Hydromatics Co) was contacted to supply up-to-date blueprints and a listing of material for this valve. Exchange of correspondence and telephone calls did not provide additional up-to-date information. The valve was disassembled and reworked by Bell to be compatible with the system. After check out in the system an excessive oxidizer leakage was found at the ball seat. The valve was then replaced with a Bell designed poppet type dual, jettison valve, B/P No. 62-472-034 (Figure 125). This valve was used in all the system tests. Disassembly of the valve disclosed no adverse effects.

(b)   Valve Assembly, Bleed Valve (59-472-275)

These valves were used in both the UDMH and N_2O_4 flow systems. No flow data was recorded for these valves since their function in the flow system was to bleed the propellant lines. These valves are constructed of type 304 stainless steel with a teflon bushing (Figure 128). Disassembly of these valves disclosed no adverse effects.

(2)   Valves for UDMH service only

(a)   Pressure Switch Assembly (62-472-667-1 and 5, Figure 130)

These switches were incorporated in the flow system to check compatibility of materials and not to monitor any pressure actuating sequence.

Upon disassembly (Figure 150), it was found that there were no adverse effects from the UDMH to the internal portion of the type 300 series stainless steel bellows. However, corrosion was found in the outer portions outside of the Bellows Assembly. This was attributed to the inadvertent operation of the water deluge system. This water deluge system was installed to flush the external portions of the flow system should N_2O_4 or UDMH leakage occur. The design of the pressure switch assembly allows the presence of water with the possibility of N_2O_4 or UDMH fumes. This caused the electrical and other internal parts to become corroded. It is concluded that pressure switches that are to be used in a system where a water deluge is required for removal of propellant fumes, or in a system where propellant vapor or fumes could be present, should have internal electrical portions either hermetically sealed, or confined by compatible gaskets.

(3) Valves used for N_2O_4 Service Only

(a) Pressure Switch Assembly (62-472-667-3 and 7, Figure 130)

These switches were used in the N_2O_4 flow system to check compatibility of materials and not to monitor any valve pressure actuating sequences.

Upon disassembly of the pressure switch (Figure 149), salt formations were found in the internal portions of the type 300 series stainless steel bellows. There was also corrosion on the outside of the bellows and in the internal portions of the pressure switch assembly. A pressure test of the bellows with N_2 gas, after disassembly of the -3 switch assembly, disclosed a slight leak on the welded joint at the junction of the bellows and the end cap.

This leakage was attributed to the fact that these pressure switches were several years old and had seen service in nitric acid and with other propellants, along with the probability that this weld initially may have been of marginal quality.

The corrosion in the internal portion of the pressure switch assembly outside of the bellows was attributed to the water deluge system, as explained under pressure switches in UDMH service.

It is concluded that pressure switches that are to be used in a system where a water deluge is required for removal of propellant fumes, or in a system where propellant vapor or fumes could be present, should have internal electrical portions either hermetically sealed, or confined by compatible gaskets.

(4) Pressurization Valves for UDMH and N_2O_4 Flow System

(a) Valve, Cross, N_2 Fill and High Pressure Jettison (62-472-671)

This valve was used as a gas fill valve. Since only nitrogen gas came in contact with the internal portions of the valve, disassembly disclosed no adverse effects.

(b) Valve Assembly – Solenoid Actuating, 3-Way (62-472-412, Figure 134)

The function of this valve in the system was to open and close the gas actuated 62-472-093 valves. This valve performed satisfactorily in the system. There was no contact with UDMH or N_2O_4. Disassembly of the valve disclosed no adverse effects.

(c) Check Valve Assembly (62-472-510, Figures 135 and 155)

Used in the gas pressure line to the oxidizer tank.

(d) Check Valve Assembly (62-472-089, Figure 127)

Used in the gas pressure line to the oxidizer tank.

These valves saw only nitrogen gas in contact with the internal portions of this valve and disassembly disclosed no adverse effects.

The following valves, originally scheduled for use in the storable propellant flow system, were not utilized for the reasons given:

(1) 56-475-548 Fuel Line Filter – Constructed of brass material which was not compatible with UDMH.

(2) 62-475-087 Oxidizer Suction Line Strainer – Constructed of compatible stainless steel material ' . was not utilized because of the unavailability of the suction line that mounted the strainer.

(3) 56-472-750 Oxidizer Fill Adapter, 62-472-295 Oxidizer Vent Adapter, and 62-472-297 Fuel Vent Adapter – constructed of compatible materials but were not utilized because of the unavailability of the mating ground service fill nozzles and vent adapters.

In addition to the above reasons, these valves were originally used in the Rascal Missile System for adapting to ground service equipment for loading and venting propellants. To successfully integrate them in this flow system, new hardware would have had to be fabricated.

Since we were conducting flow tests simulating a typical rocket engine system with higher flows and pressures than would be used for loading missile tanks, these valves were omitted.

An analysis of the materials used in the Fuel Fill Disconnect (B/P No. 56-472-662) and the Fuel Fill Nozzle (B/P No. 4-2650-10) showed the presence of materials incompatible with UDMH, particularly the aluminum, bronze, and brass parts and seals of the valve. The original manufacturer of the valve (Parker Aircraft Co) was contacted to supply compatible replacement parts. It was learned that these parts were not available as off-the-shelf items, and would therefore require long delivery dates.

As a result, it was determined not to use the ground service valves, listed above, in the system since it was felt sufficient data could be obtained with the other Rascal flow control valves.

b.   Frangible Disc Storage Tests

As part of system testing, frangible discs were subjected to N_2O_4 and UDMH storage for periods of three, six, and nine months.

The frangible discs used to determine the corrosion and/or burst changes caused by exposure to N_2O_4 are currently used in a system which uses inhibited red fuming nitric acid as an oxidizer. Six specially designed fixtures were fabricated for these storage tests (Figure 156).

The design of these fixtures was such that a measured quantity of N_2O_4 was contained in a chamber having one frangible disc as a seal on one end and a standard plug on the other end. The frangible disc was secured between two serrated surfaces on each half of the fixture which make the seal between the N_2O_4 and atmosphere. The face of each disc exposed to N_2O_4 is made of type 1100-0 aluminum. Any attack of the N_2O_4 on the disc would result in external leakage or different rupture values.

These six fixtures were numbered and placed in storage for the three-, six-, and nine-month periods at ambient conditions. A daily visual inspection was made on the fixtures. Two of the fixtures completed their allotted three-month storage. These fixtures were disassembled and the discs were inspected, measured, and weighed. Analysis of the N_2O_4 before and after test showed only slight changes in composition.

The visual inspection of the discs indicated no changes in their physical appearance due to corrosion. This was substantiated when negligible changes in size and weight were found. The test discs were ruptured with water and compared with the burst pressure of a reference disc. The burst pressure of the test discs was within the design limits of these discs. These data are reported in Table 89.

The rated flow for these discs after rupture was 30 lb/sec at an inlet pressure of 900 psig. Fixture 201 was subjected to a flow of 40 pounds per second at inlet pressure of 900 psig for one minute after rupture. Upon investigation of the ruptured discs, Figure 157, the break was normal and clean and there was no apparent effect of the fluid velocity on the ruptured lip.

After two other fixtures, No. 203 and 204, completed the allotted six-month storage, they were disassembled and the discs were inspected and weighed. Analysis of the N_2O_4 before and after test showed only slight changes in composition. The visual inspection of the discs indicated no changes in their physical appearance due to corrosion, and the weight increases were insignificant (Table 89). The frangible discs used in this storage test were also of a laminated construction consisting of the foil or disc cemented to the retainer lip.

There was no measurement of the thickness of the discs after this six-month storage because the discs showed some slight separation of the foil and retainer after disassembly (Figure 158) and before rupture, making recording of this data impossible. The separation was caused by an improper bond of the two parts of the disc assembly, and the pressure test to insure a leak proof seal of the disc and fixture.

The test discs were ruptured with water and compared with the burst pressure of the reference disc. The burst pressure of the test discs was approximately 15% higher than the design limits of these discs. Figure 159 shows the abnormal break of these discs.

Since the inception of this program and because of the recent high rate of poor cycle welds, batch sampling under rigid Bell Aerosystem's quality control is being followed to assure compliance with rated burst values. This includes manufacture of discs in batches with recording of manufacture and cure dates, and actual rupture of a certain number of each batch. Deviation from rated rupture pressure causes rejection of the entire batch.

The discs used in this storage test were procured before the inception of batch sampling, so it is possible that several discs being used for conducting these tests may have poor cycle welds.

Following rupture, fixture No. 203 was subjected to the rated flow of 30 lb/sec at an inlet pressure of 900 psig for one minute. Fixture No. 204 was subjected to an increase flow of 40 lb/sec at an inlet pressure of 900 psig for one minute.

Upon investigation of the ruptured discs, the break was uneven and torn. This resulted from the improper bonding of the disc and foil and the higher pressure necessary for rupture.

There was no apparent effect of the fluid velocity on the ruptured lip after storage.

When the final two fixtures, No. 205 and 206, completed nine months' storage, they were disassembled and the discs were inspected and weighed. Analysis of the N_2O_4 before and after test showed only slight changes in composition.

The visual inspection of the disc showed no visible changes in fixture No. 205. Fixture No. 206 had a slight salt deposit on the N_2O_4 side. Dimensional changes and weight changes on the fixture No. 205 were negligible. Disc No. 206 showed a slight increase in weight and thickness due to salt deposit.

The discs were reassembled in their respective fixtures and ruptured. Rupture values of the test discs were within rated values of a reference disc (Table 89). Following rupture (Figure 160), fixture No. 205 was subjected to the rated flow of 30 lb/sec at an inlet pressure of 900 psig for one minute.

Upon investigation of the ruptured discs, the break was even and clean and there was no apparent effect of the fluid velocity on the ruptured lip.

As a result of this frangible disc storage program, it is concluded that there is no apparent adverse effect of N_2O_4 upon a production type frangible disc when stored at ambient conditions in N_2O_4 for a nine-month period.

The frangible discs used to determine the corrosion and/or burst changes caused by exposure to UDMH were Rascal production type discs. Six Rascal N_2H_4 pack assemblies (Figure 161) were reworked for the UDMH storage program by incorporating seals and lubricants compatible with UDMH.

As with the N_2O_4 frangible disc tests, these packs were fitted with frangible discs previously weighed and measured, and filled with previously analyzed UDMH.

The design of these pack assemblies was such that a measured quantity of UDMH was sealed between two frangible discs. The seals between the UDMH and atmosphere are the frangible discs which are held in place by external nuts torqued to measured values. The face of each disc exposed to UDMH is made of type 1100-0 aluminum.

Attack of the UDMH on the frangible discs or rubber O-rings would result in leakage and possibly affect the rated burst pressure of the discs.

These six fixtures were numbered, filled with UDMH, and placed in storage for the three-, six-, and nine-month periods at ambient conditions.

A daily visual inspection was made of the fixtures. After three months' storage, two of the fixtures were disassembled and the discs were inspected, measured, and weighed. Data obtained are listed in Table 90.

UDMH analyses before and after test are reported in Table 91. With the exception of a yellow discoloration and a decrease in percent transmission, the UDMH from each test fixture met Military Specifications (Reference 90). Propellant discoloration was probably caused by contact with butyl rubber O-rings.

A visual inspection of the discs indicated no changes in their physical appearance due to corrosion. Dimensional changes were negligible and with the exception of disc 2, in fixture No. 202, which exhibited a slight leak after 60 days, weight changes were negligible. The weight increase, approximately 0.7%, can be attributed to the absorption of UDMH by the exposed cycle-weld cement on the opposite side of the disc. A pressure check of 10 psig, made before disassembly of the leaking fixture, showed no increase in the leakage. For this reason, it was concluded that leakage was caused by improper seals between the frangible disc and the fixture.

Again, these discs were ruptured with water and compared with the burst pressure of a reference disc. The burst pressure of the test discs was within the design limits of these discs. The rated flow for these discs after rupture was three pounds per second at an inlet pressure of 750 psig.

Fixture No. 201 was subjected to this flow for a duration of one minute after rupture, and fixture No. 202 was subjected to a flow of 30 rated, or four pounds per second, at inlet pressure of 750 psig for one minute duration after rupture. Upon investigation of the ruptured discs, the break was normal and clean and there was no apparent effect of the fluid velocity on the ruptured lip (Figure 162). After two other fixtures, No. 203 and 204, completed six months' storage, they were disassembled and the discs were inspected for corrosion, measured, and weighed. Data obtained are recorded in Table 90.

The UDMH used in this test was inadvertently dumped after storage. Therefore, no data on the UDMH analysis after storage is available.

A visual inspection of the discs indicated no changes in physical appearance due to corrosion. Dimensional changes were negligible and the weight increases were insignificant. Figure 163 is a photograph of the discs after the six-months' exposure.

The discs were reassembled in the respective fixtures and ruptured with water. Higher rupture values than rated for fixture No. 203 were attributed to improper cycle welding of the downstream No. 2 disc.

The rupture discs used in these storage tests were of a laminated construction consisting of the foil or disc cemented to the retainer or lip. This is similar to the discs used in the N_2O_4 tests.

The No. 2 disc in fixture No. 203 showed a slight separation of the foil and retainer after disassembly. This was caused by an improper bond of the two parts of the disc assembly. The pressure test to insure a leak-proof seal of the disc and fixture caused this separation.

This resulted in the slightly higher pressure necessary to rupture the discs in fixture No. 203 as is shown in the rupture pressure column of Table 90.

As is stated in the N_2O_4 frangible disc storage test, batch sampling under rigid Bell Aerosystems control is being followed to assure a better quality disc. Here again, it is possible that inferior quality discs were used for this test.

Following rupture, fixture No. 203 was subjected to the rated flow of 3 lb/sec at an inlet pressure of 750 psig for one minute, and fixture No. 204 was subjected to an increased flow of 4 lb/sec at an inlet pressure of 750 psig for one minute.

Upon investigation of the ruptured discs, the No. 2 disc in fixture No. 203 showed an uneven and torn break (Figure 164). This resulted from the improper bonding of the disc and foil, and the higher pressure necessary for rupture. The break in the No. 1 disc in fixture No. 203 was normal. The breaks in both discs in fixture No. 204 (Figure 164) were normal and clean, and the rupture pressure was within design limits.

There was no apparent effect of the fluid velocity on the ruptured lips after storage.

The final two fixtures, No. 205 and 206, completed nine months' storage and were disassembled. The frangible discs were removed, weighed, and measured. Analysis of the UDMH after test showed that the propellant met specifications except for a slight yellow discoloration (Table 91).

Visual inspection of the discs showed no visible changes. The surface of the discs exposed to UDMH was bright and clean. Comparison of the weights of the discs showed a slight in-

crease after nine months' storage. An overnight test was made on the discs consisting of exposure in a beaker to a slight stream of N_2 gas to vaporize UDMH absorbed in the frangible disc material. No significant weight change resulted.

The discs were reassembled into their respective fixtures and ruptured. Following rupture, fixture No. 205 was subjected to the rated flow of 3 lb/sec at inlet pressure of 750 psig for one minute. Fixture No. 206 was subjected to a flow of 4 lb/sec at inlet pressure of 750 psig for approximately one minute.

Upon investigation of the ruptured discs, the break was even and clean and there was no apparent effect of the fluid velocity on the ruptured lip (Figure 165).

As a result of this frangible disc storage program, it is concluded that there is no apparent effect of UDMH upon a production type frangible disc when stored at ambient conditions in UDMH for a nine-month period.

III. CONCLUSIONS AND RECOMMENDATIONS

N_2H_4 and UDMH are insensitive to shock at ambient temperatures and after storage at 160°F for three months.

Generally, no serious problems are involved in finding metals of construction for service with N_2O_4, N_2H_4, and UDMH provided that the propellants are used in their anhydrous state and temperatures do not exceed 160°F (65°F for N_2O_4).

Teflon is considered the best available plastic material for use with the three propellants. Among elastomers, butyl rubber 805-70 obtained from PARCO was found to be satisfactory for service with the fuels. Silastic LS-53 and Stillman Rubber compound TH1057 are considered promising elastomers for limited service with N_2O_4. However, no fully compatible elastomer for N_2O_4 service has been found, and further testing before use in a component is recommended.

Based on field experience and extensive laboratory tests, three lubricants were found to be suitable for UDMH and N_2H_4 service. For N_2O_4, the only lubricant found that might find limited service was molybdenum disulfide.

It is recommended that efforts be continued to find plastics, elastomers, and lubricants compatible with the three propellants, particularly N_2O_4. In addition, it is recommended that testing be conducted to resolve controversial materials compatibility data.

It is recommended that more elaborate material compatibility tests be performed with those materials considered satisfactory for short-term service with the propellants. Such testing should include measurements of mechanical properties, determining optimum compatibility time and temperature, and determining amount of water contamination that can be tolerated in the propellants without having adverse effects on the materials.

Certain constituents of air were found to react with the propellants. The effect of contaminants such as stainless steel chips, aluminum chips, and lint in the propellants was negligible. N_2O_4, UDMH, and N_2H_4 were pressurized with hot nitrogen (1000°F) under 1000 psig with no mishaps. However, during prerun temperature conditioning with the N_2H_4 (in 347 stainless steel tank) at 150°F and the ullage temperature at approximately 290°F, a tank rupture occurred.

Two explosions were encountered during high temperature (300°F) tests with N_2H_4. One explosion occurred in type 347 stainless steel tank and the other in PH 15-7 Mo stainless steel tank. The causes were attributed to catalytic decomposition. N_2H_4 decomposition also occurred in 6061-T6 aluminum and C 120 AV titanium, but the decomposition was not explosive under the conditions tested.

UDMH was stored in 6061-T6 aluminum, C 120 AV titanium, type 347 stainless steel, and PH 15-7 Mo stainless steel at approximately 3000°F for three months exhibiting only slight decomposition and small pressure rises. The metals are placed in order of preference. Anhydrous N_2O_4 at elevated temperature (270°F) in 6061-T6 aluminum, 347 stainless steel, and PH 15-7 Mo stainless steel exhibited only vapor pressure. Absorption of a slight amount of moisture at this temperature will cause corrosion inside the tanks. Titanium, however, should not be used with N_2O_4 until experimental data is available disproving the possibility of forming sensitive deposits.

The three propellants were stored outdoors where temperatures fluctuated from 0 F to approximately 90 F for six months in 10-gallon, 6061-T6 aluminum and PH 15-7 Mo stainless steel drums. There was no significant change in the propellant quality after this period and visual inspection of the inside of each tank revealed no corrosion. The fuels were stored at 160 F for 3 months in identical drums with little or no propellant decomposition detected. Visual inspection of the inside of each drum showed no corrosion. N_2O_4 was stored at 70 10 F for 3 months in identical drums with no changes in propellant quality and no metal attack.

Based on flow and exposure tests with RASCAL type hardware converted to operate with N_2O_4/UDMH (merely changing seal materials as noted in this report), it can be concluded that the state-of-the-art of hardware designed for fuming nitric acid (oxidizer) and JP-4 (fuel) can be utilized with liquid storables.

A total of eight shaft seal configurations were evaluated. Six configurations were of the bellows type face seal and two of the standard internal packing type face seals. The bellows type face seals having Graphitar G-39 carbon, Purebon Carbon 658RC, and glass impregnated Teflon and ceramic impregnated Teflon seal face inserts showed excellent wear qualities when run against 316 stainless steel and flame-plated chromium carbide mating rings. The bellows type face seal, in general, was superior to the standard internal packing type seal. Bellows material tested included Inconel-X, AM-350, 347 stainless steel, and 410 stainless steel. All of these materials were compatible with N_2O_4. The only problem area encountered was with the 347 stainless steel bellows which took a permanent set at the seal operating height. This is a typical characteristic of 347 stainless steel since this type stainless steel is not heat-treatable. Of the standard internal packing type seals, butyl rubber and Teflon packings were tested. It was found that the butyl rubber internal packing was severely attacked by the N_2O_4, causing excessive leakage past the packing. This was the only compatibility problem encountered during the entire seal evaluation program.

It is recommended to conduct further seal evaluations in conjunction with the proposed bearing evaluations. At this time, the evaluation should concentrate on seal face material combinations. Materials such as flame-plated aluminum oxide, flame-plated tungsten carbide and 17-7 PH stainless steel should be investigated for sealing and wear qualities run against itself and the various carbons such as Graphitar Carbon G-39 and Purebon Carbon 658RC and P5N.

Anti-friction bearings, such as ball or roller bearings made from standard SAE 52100 series bearing steel or 440C stainless steel, may be satisfactorily run and lubricated in liquid N_2O_4 under loaded conditions for extended durations. Sleeve-type bearings made from glass and graphite impregnated Teflon, although compatible with liquid N_2O_4, are only capable of small load carrying capabilities.

It is highly recommended to conduct additional bearing evaluation programs utilizing the propellants for lubrication. This type of lubrication of bearings would greatly improve the state-of-the-art of turbo-pump designs. The pump impeller shaft overhangs would be eliminated by repositioning the outboard bearings from the gear box to the pump. This would result in a much shorter, compact, lightweight turbo-pump assembly. In conjunction with these tests, various additional bearing materials should be evaluated.

The N_2O_4 pumping program was completed with partial success. T' wvitation performance with water was considerably better than with N_2O_4. Cavitation performan with N_2O_4 using helium gas and nitrogen gas for pressurization indicate better performance may obtained with helium. This correlates with the fact that the helium is less soluble in N_2O_4 than ogen. Contrary to this, one point at the start of a run using nitrogen gas indicates comparable per mance to the run using helium gas pressurization. The effect of the small system volume is not k but detrimental effect is a strong possibility. The temperature rise of approximately 2 F p .... is indicative of inadequate system volume. No material compatibility or pump seal problems were encountered. No difference in the cavitation performance was found pumping UDMH as compared to pumping water.

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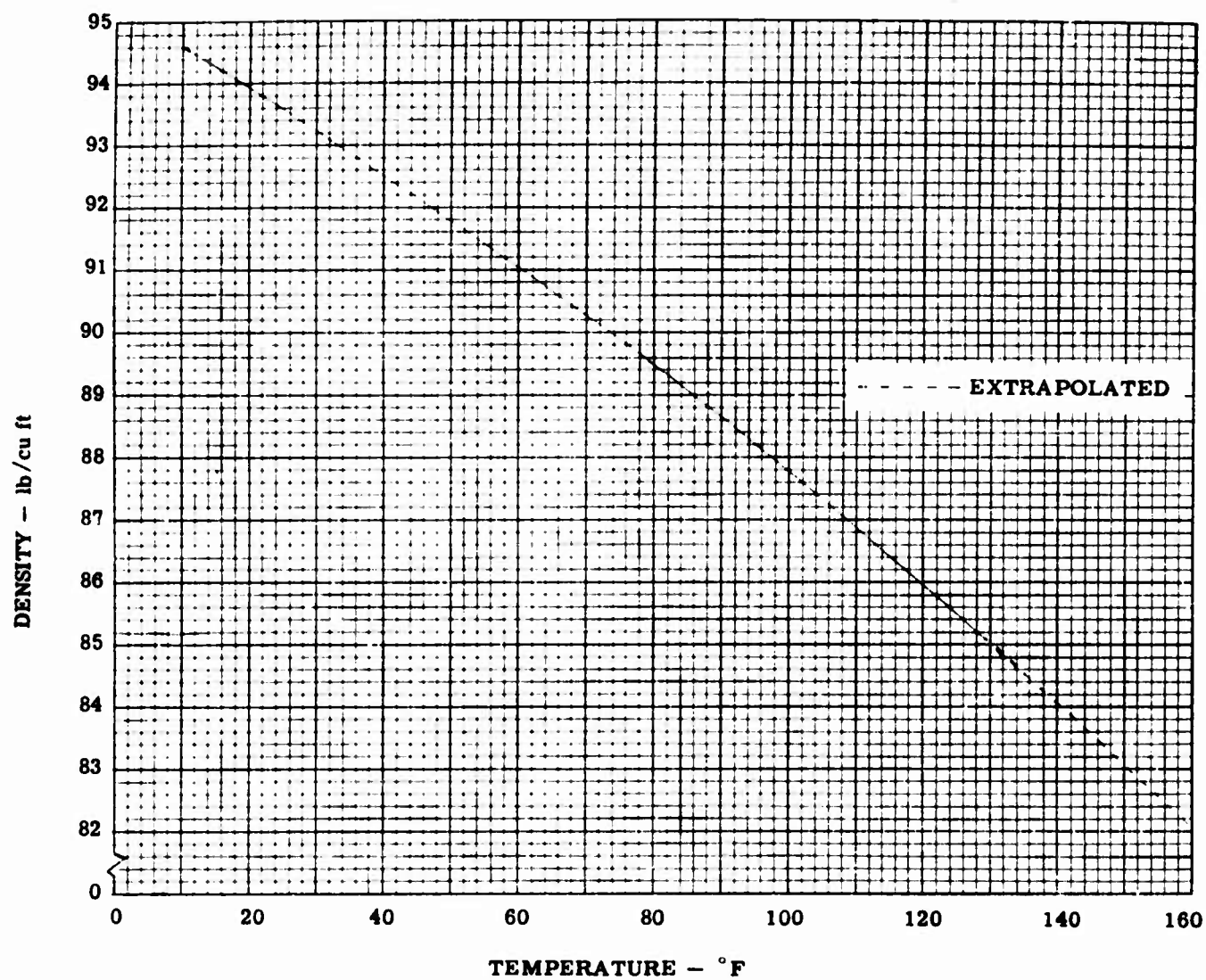
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Figure 1. N_2O_4 - Density of Liquid Under its Own Vapor Pressure
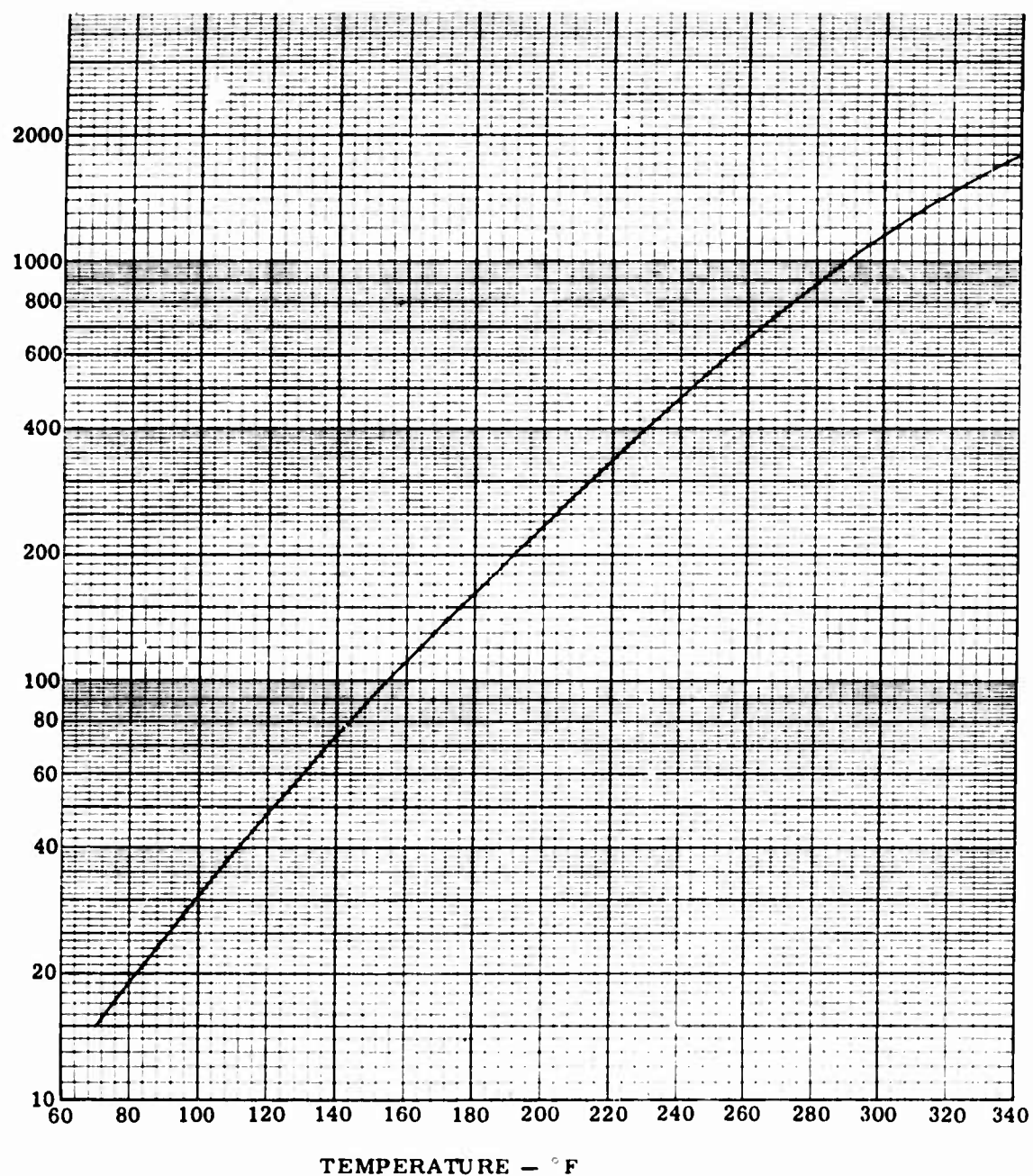
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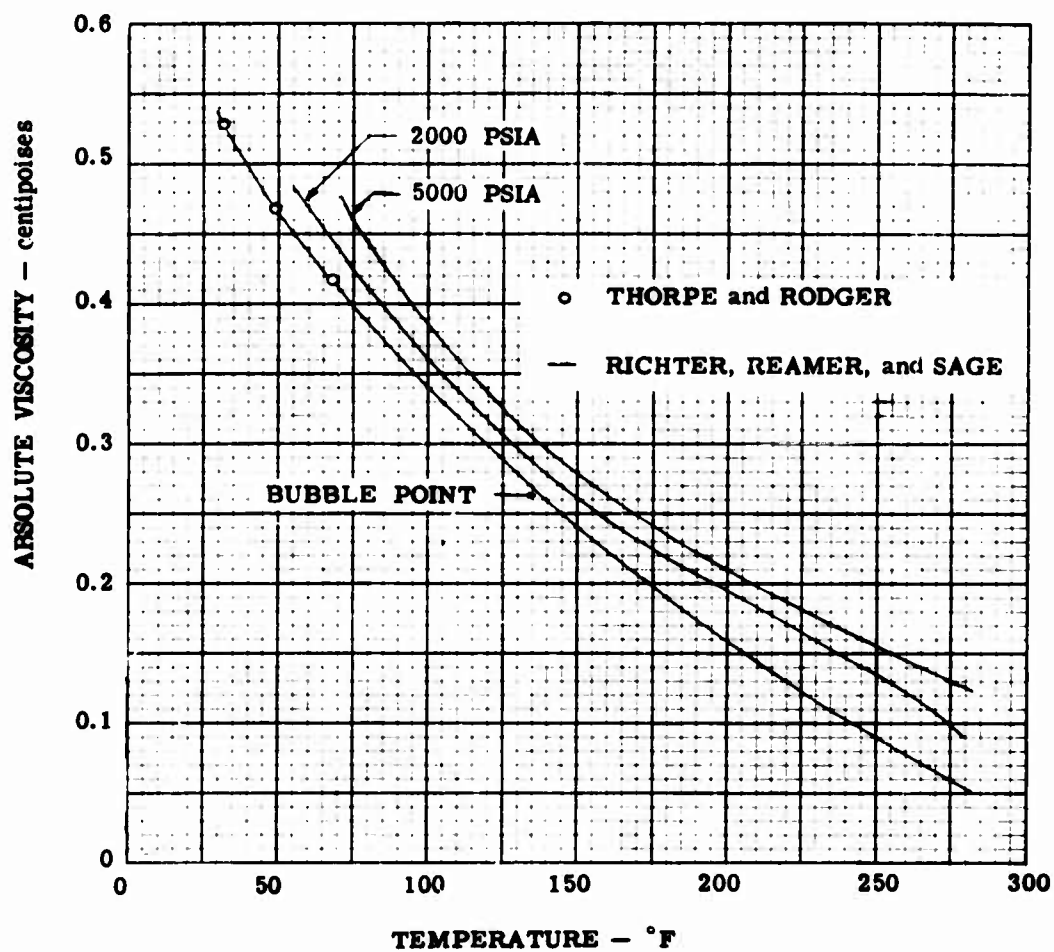
Figure 3. Effect of Temperature on Viscosity in the Liquid Phase, N_2O_4
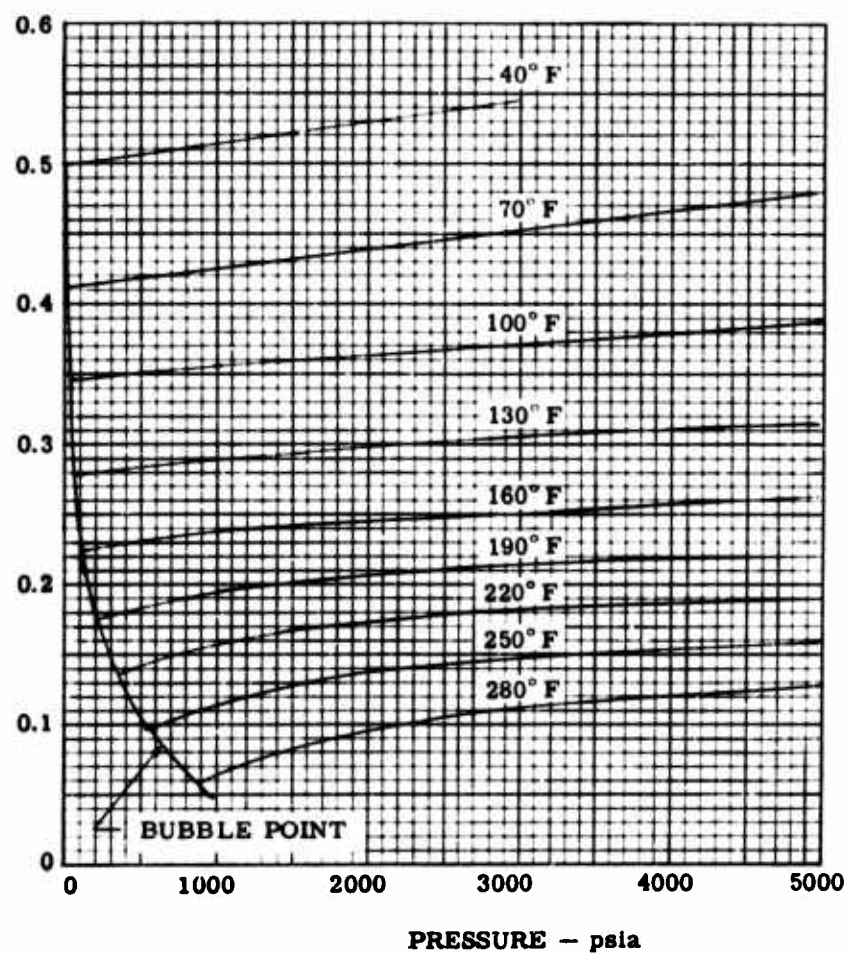
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Figure 4. Effect of Pressure on Viscosity, Liquid N_2O_4
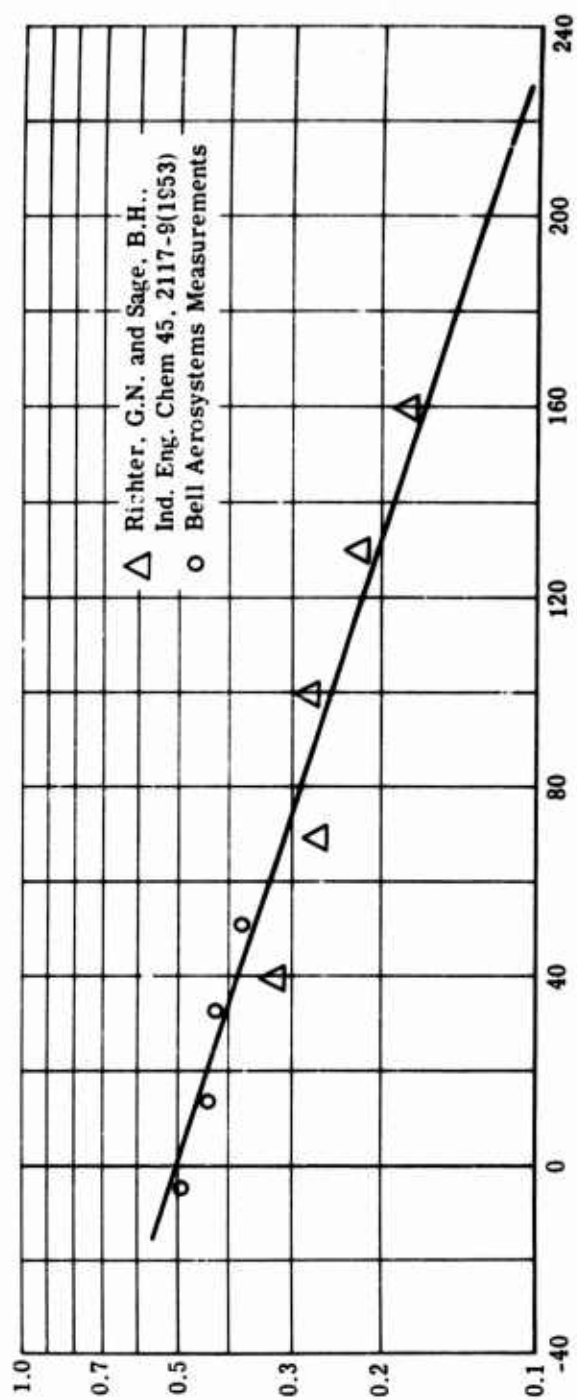
Figure 5. Viscosity of N_2O_4
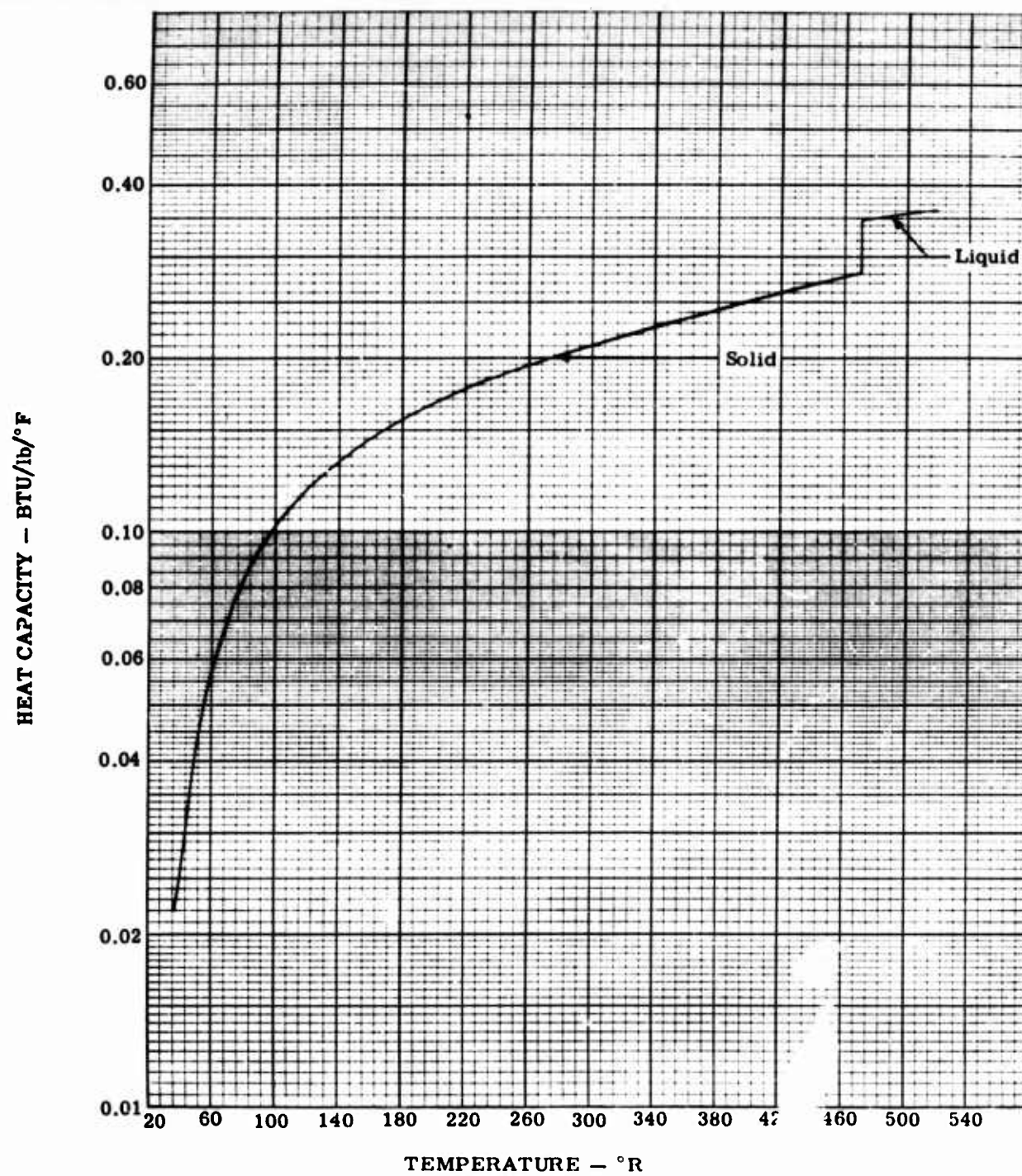
Figure 6. Heat Capacity of Liquid N_2O_4
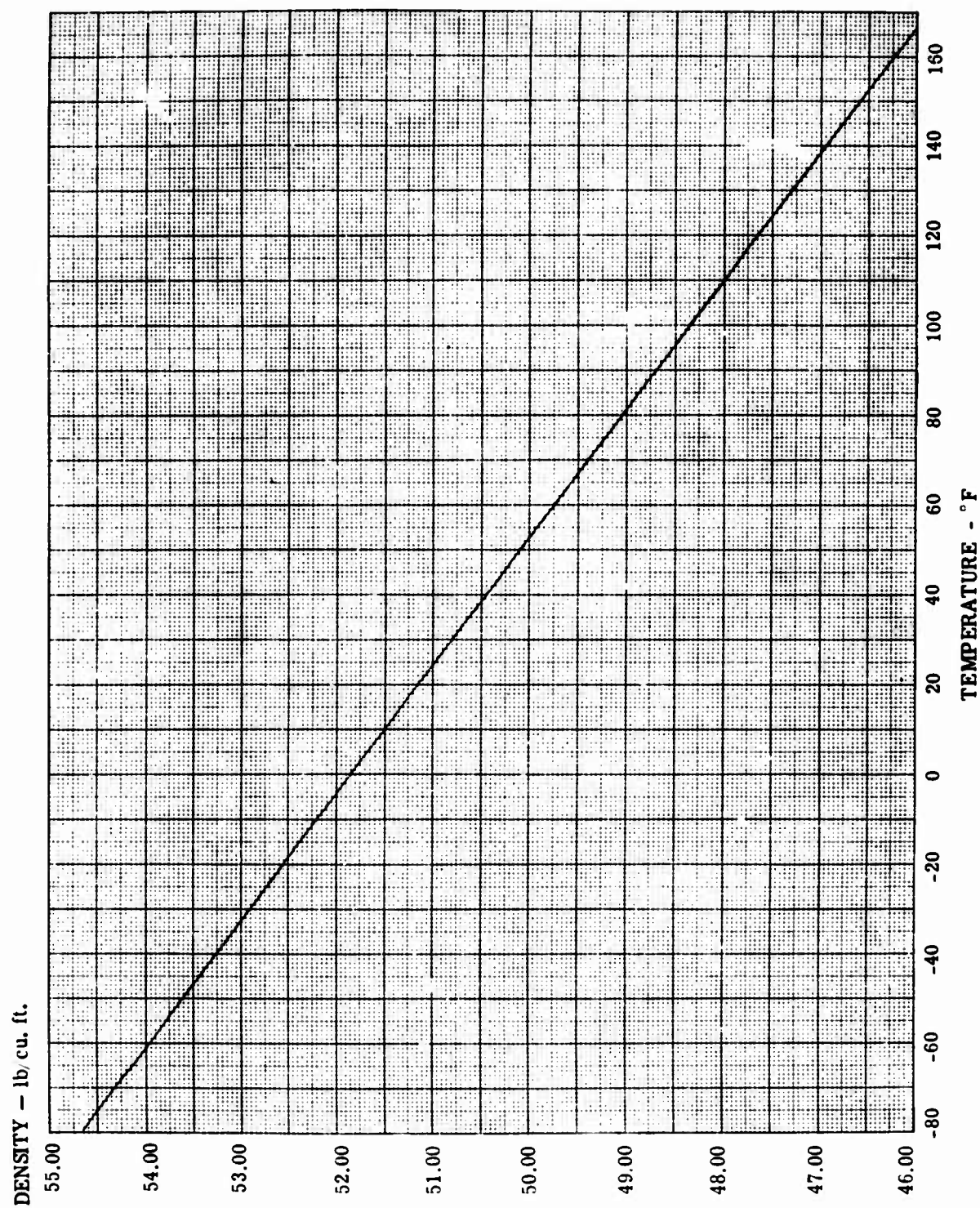
Figure 7. Density of UDMH

DENSITY — lb/cu. ft.

TEMPERATURE - °F
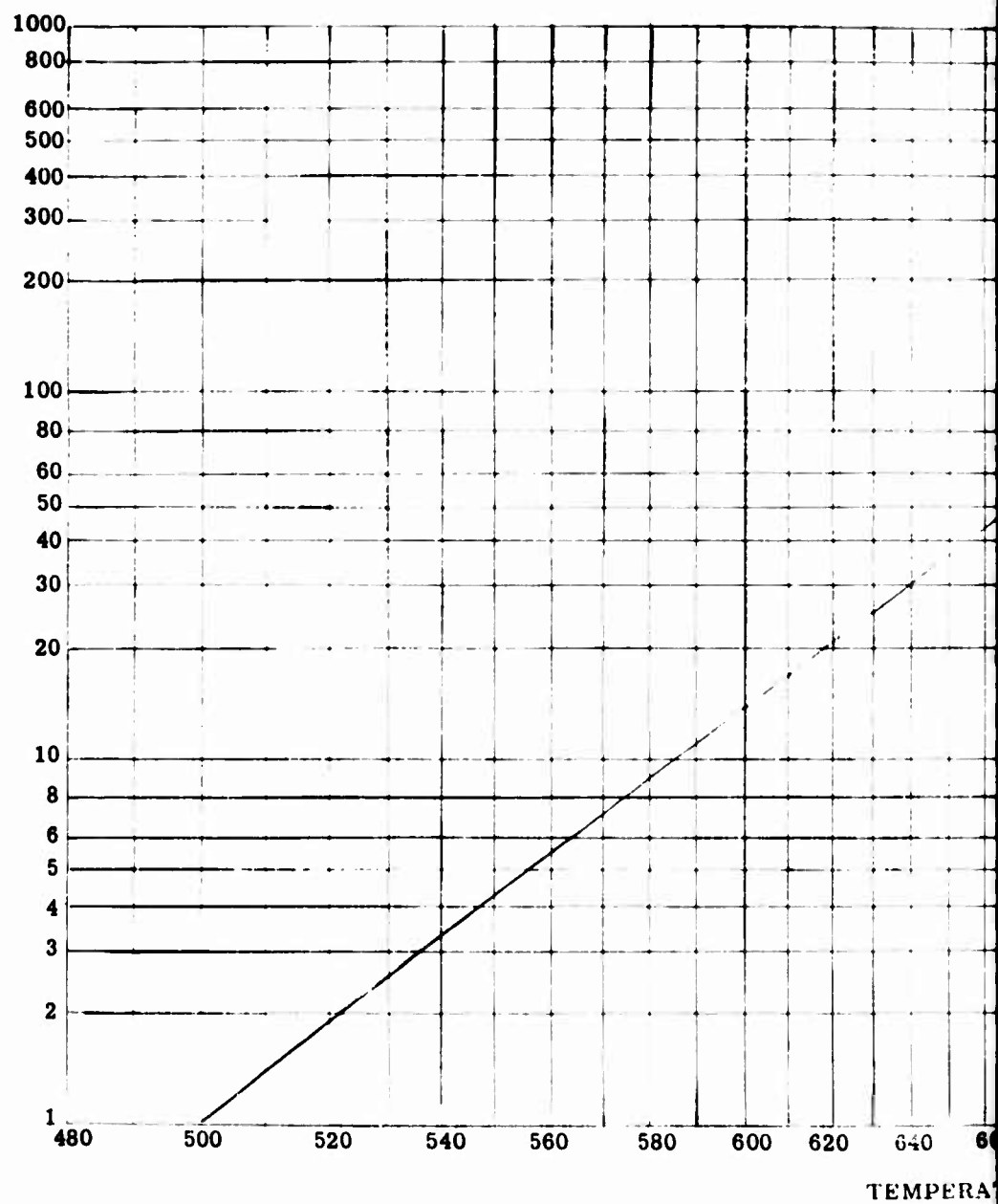
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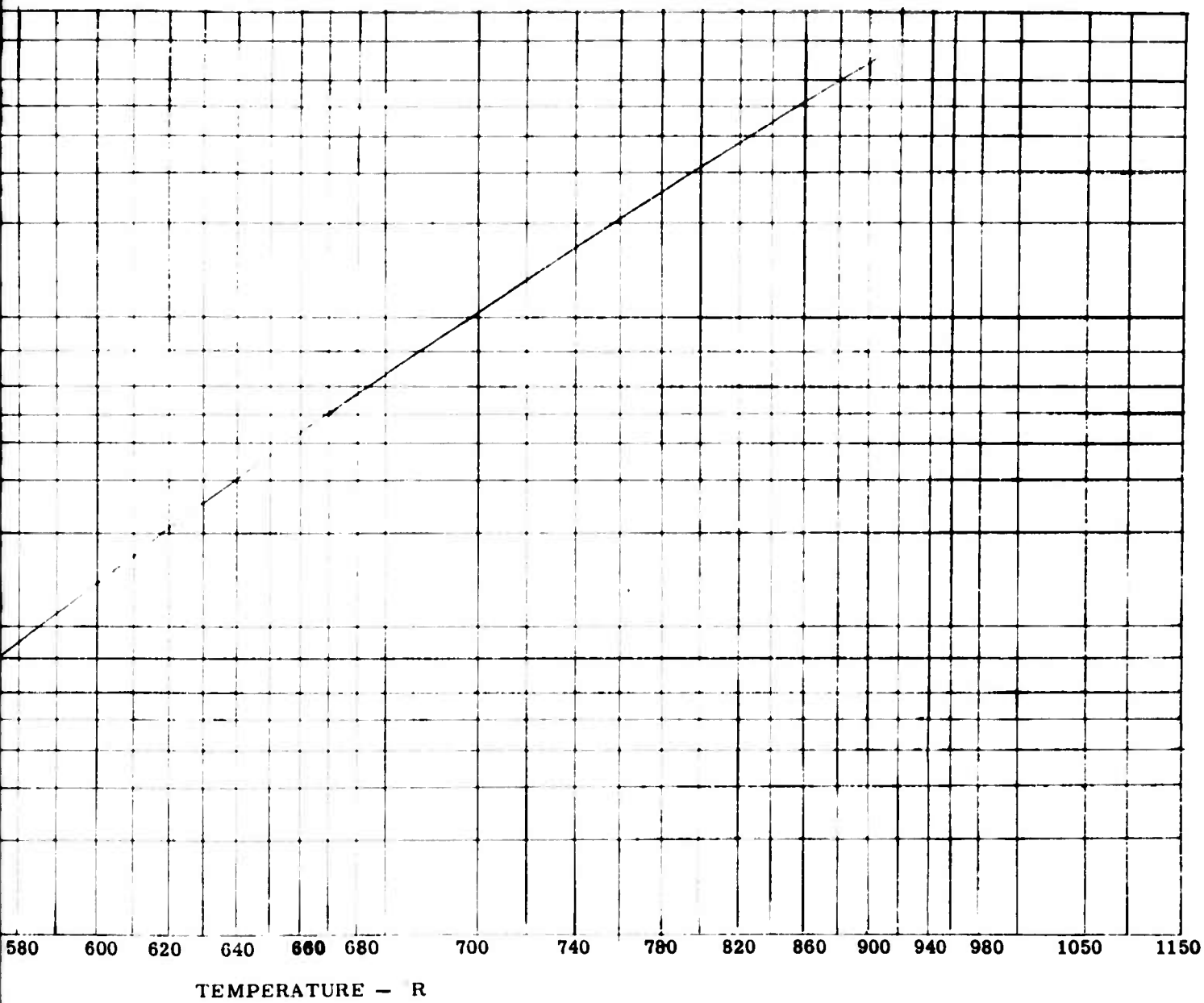
TEMPERATURE — R
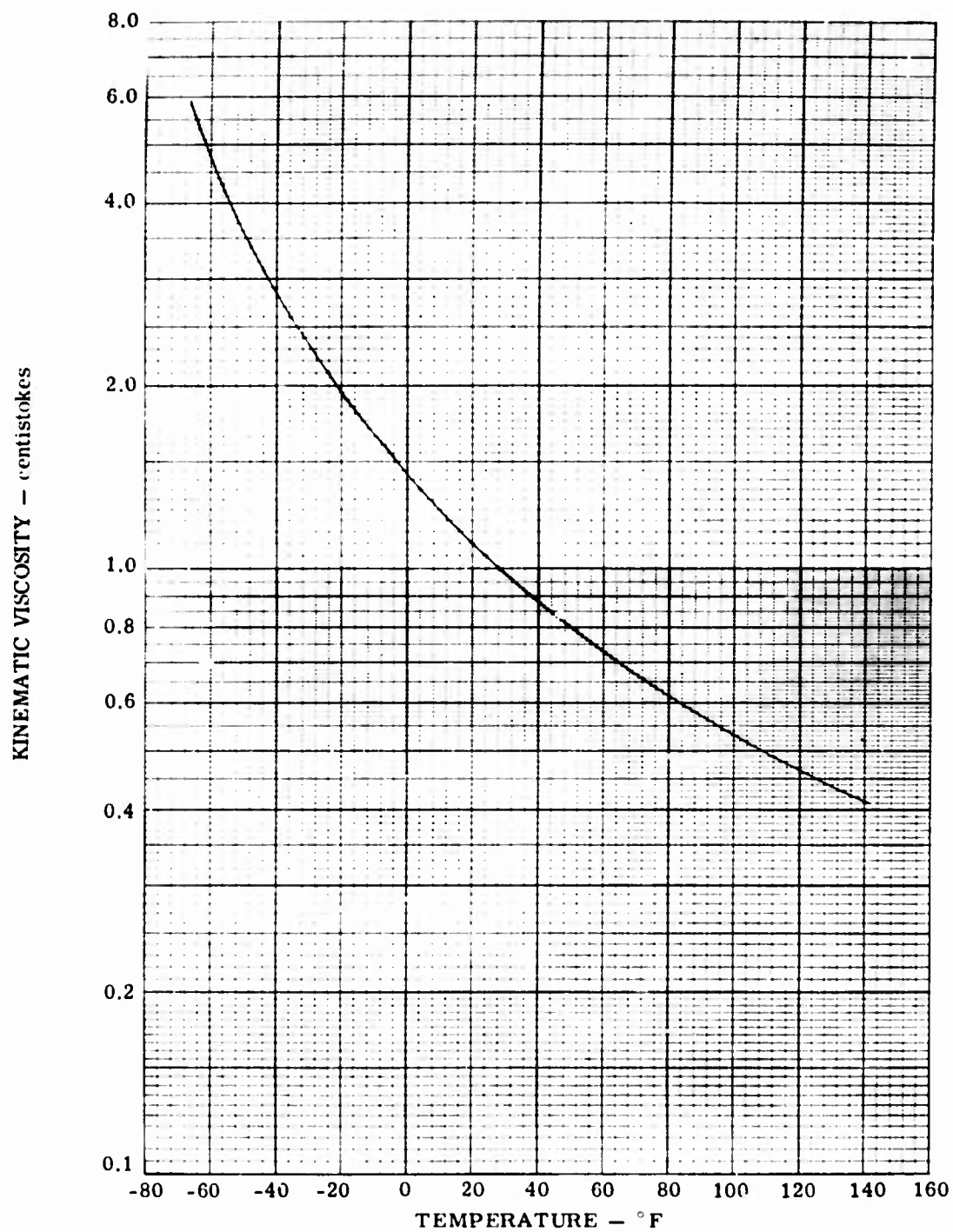
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Figure 9. UDMH Viscosity
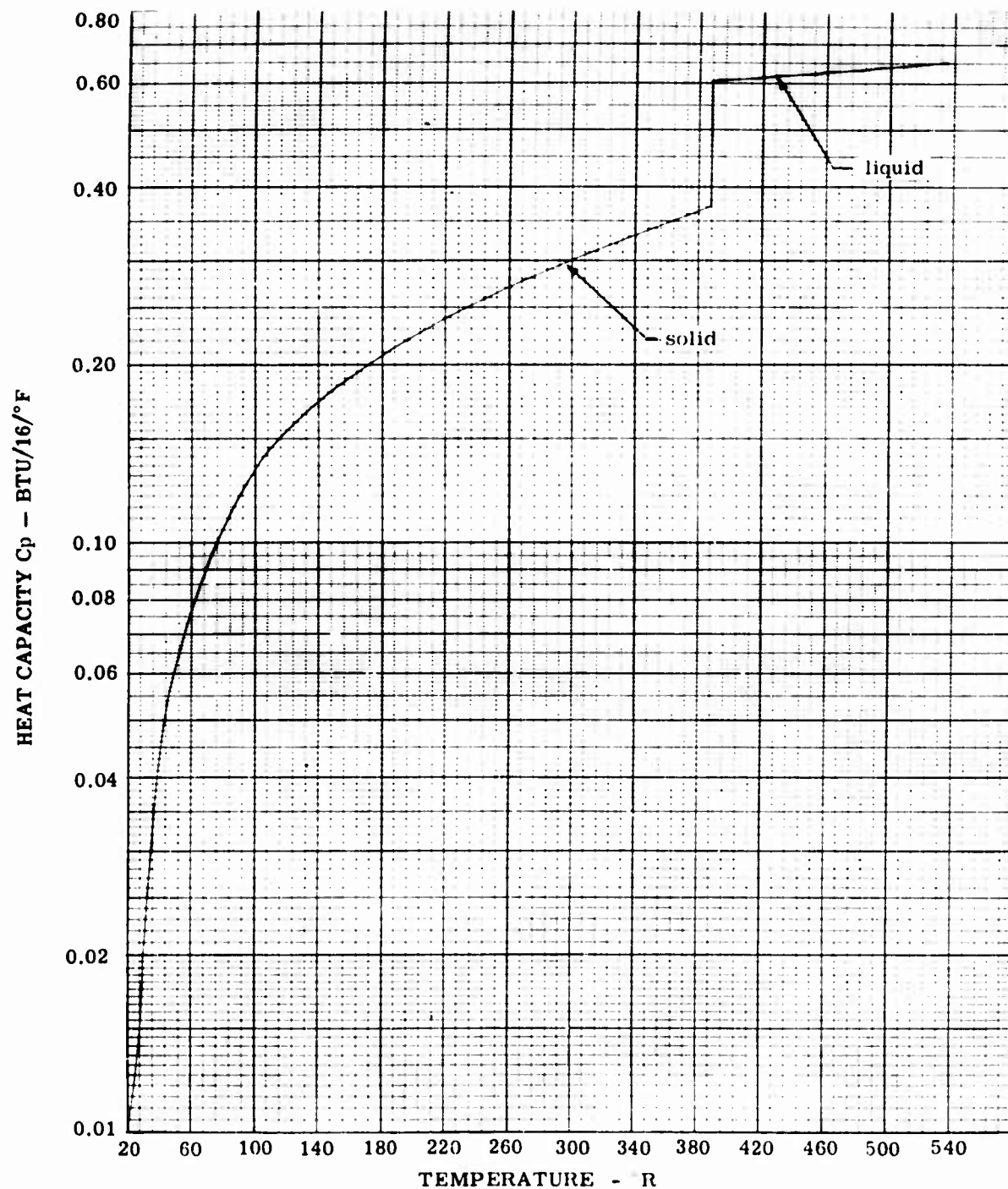
Figure 10. UDMH Solid and Liquid Heat Capacity

DENSITY — lb/cu. ft.
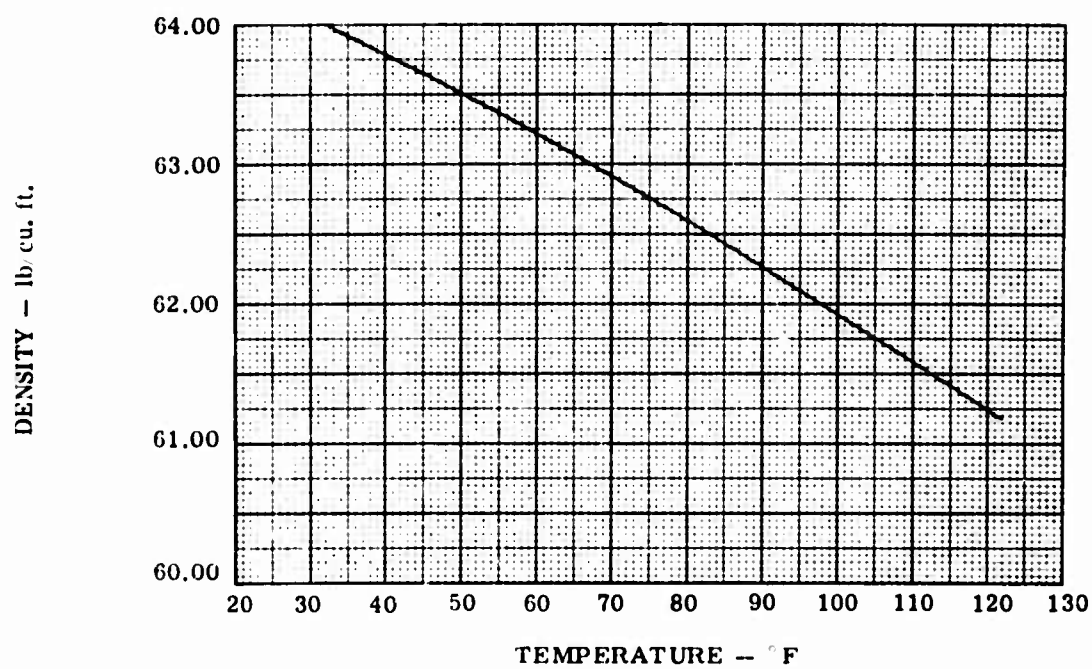
Figure 11.   Density of Liquid N_2H_4
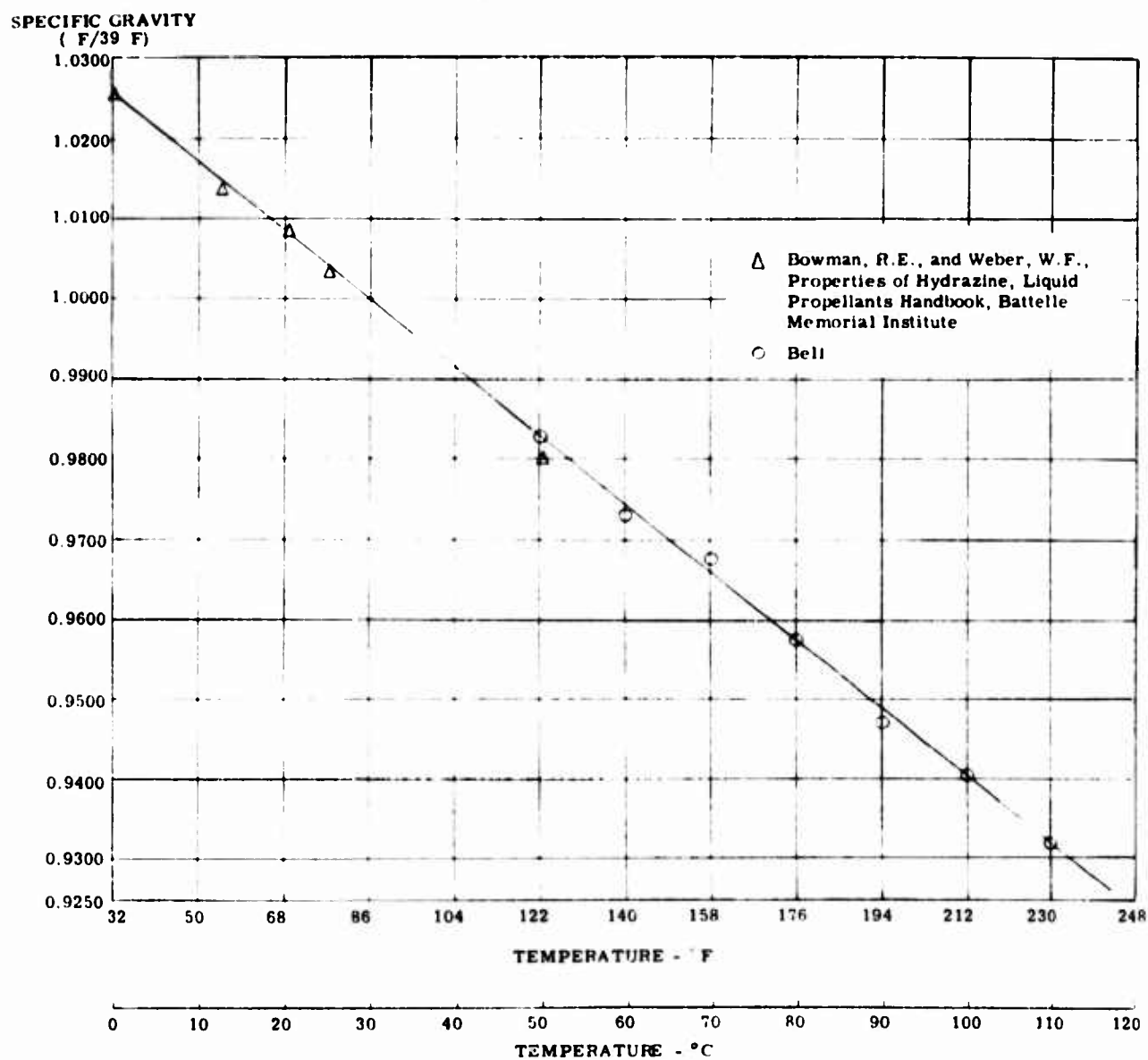
Figure 12. Specific Gravity of Anhydrous N_2H_4
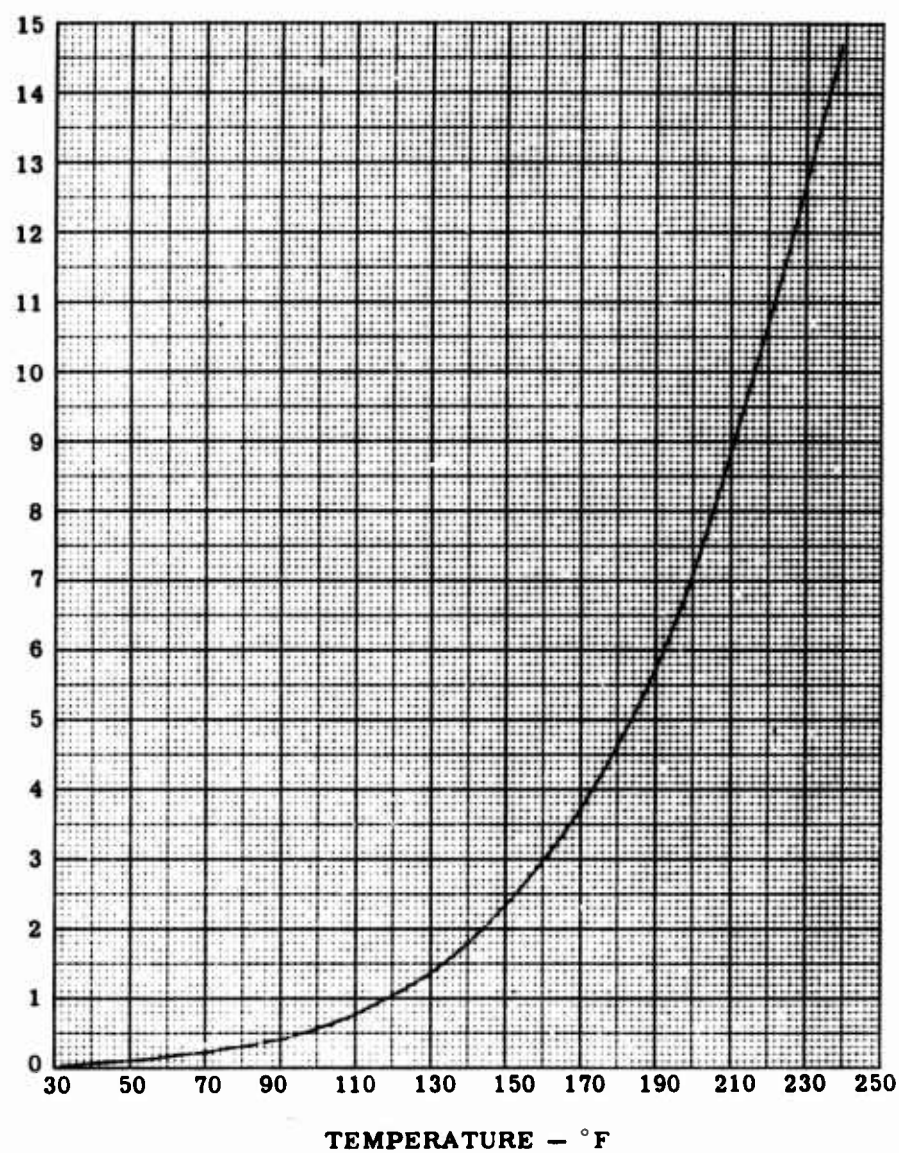
Figure 13. Vapor Pressure Versus Temperature for Anhydrous N_2H_4

VISCOSITY —

centipoises
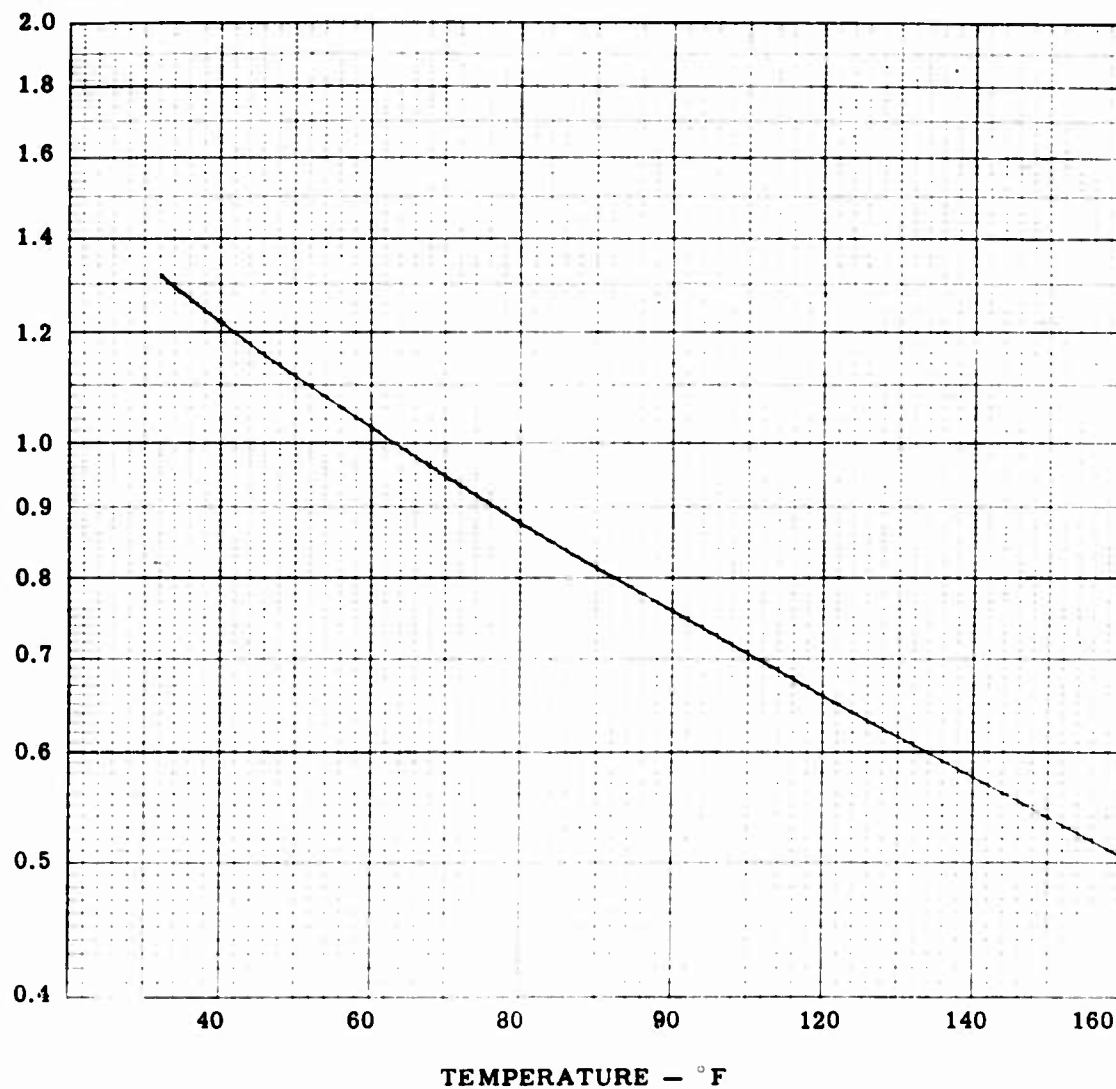
Figure 14.   Viscosity of N_2H_4 Versus Temperature
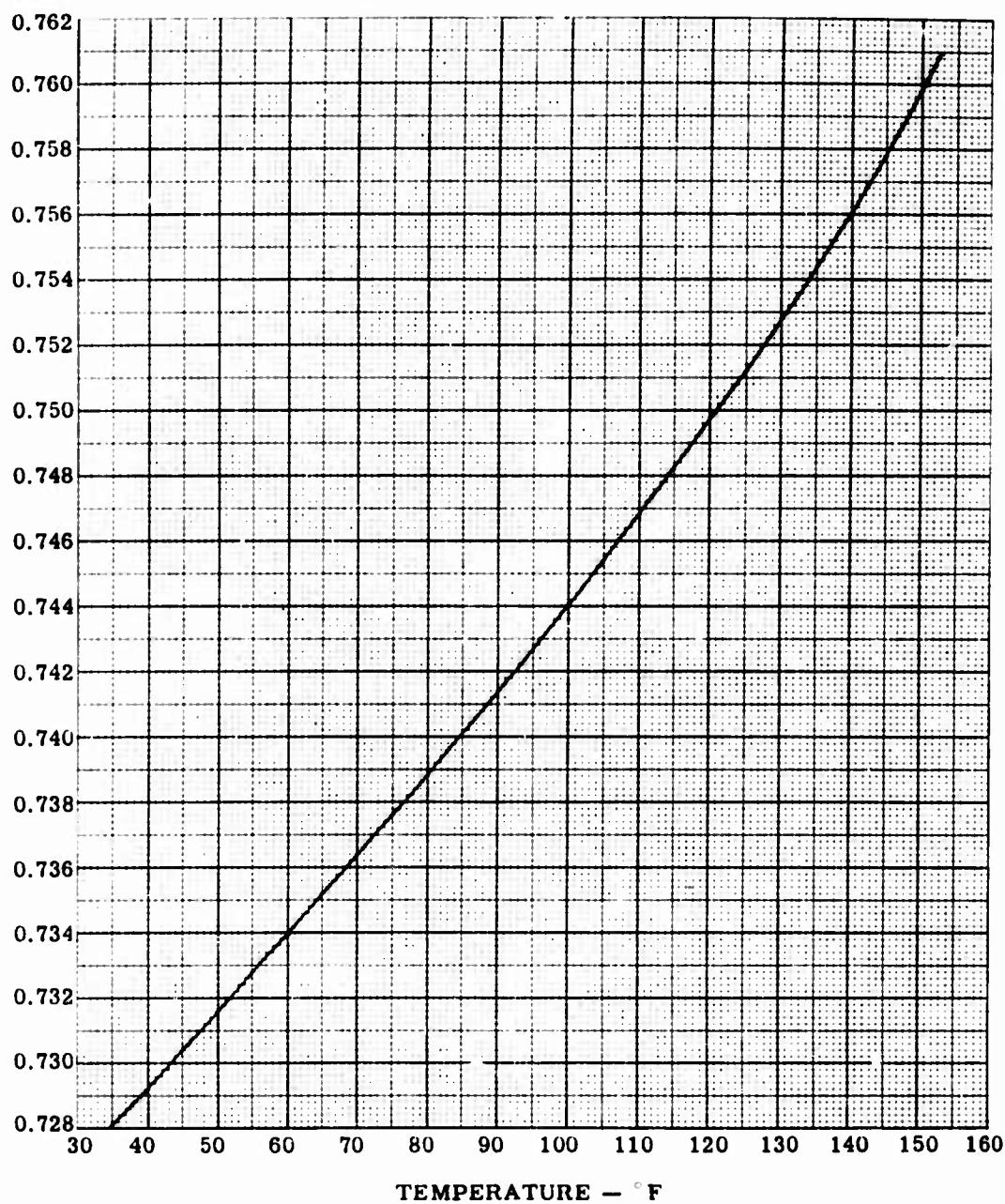
Figure 15. Heat Capacity Versus Temperature for N_2H_4 Reference 7
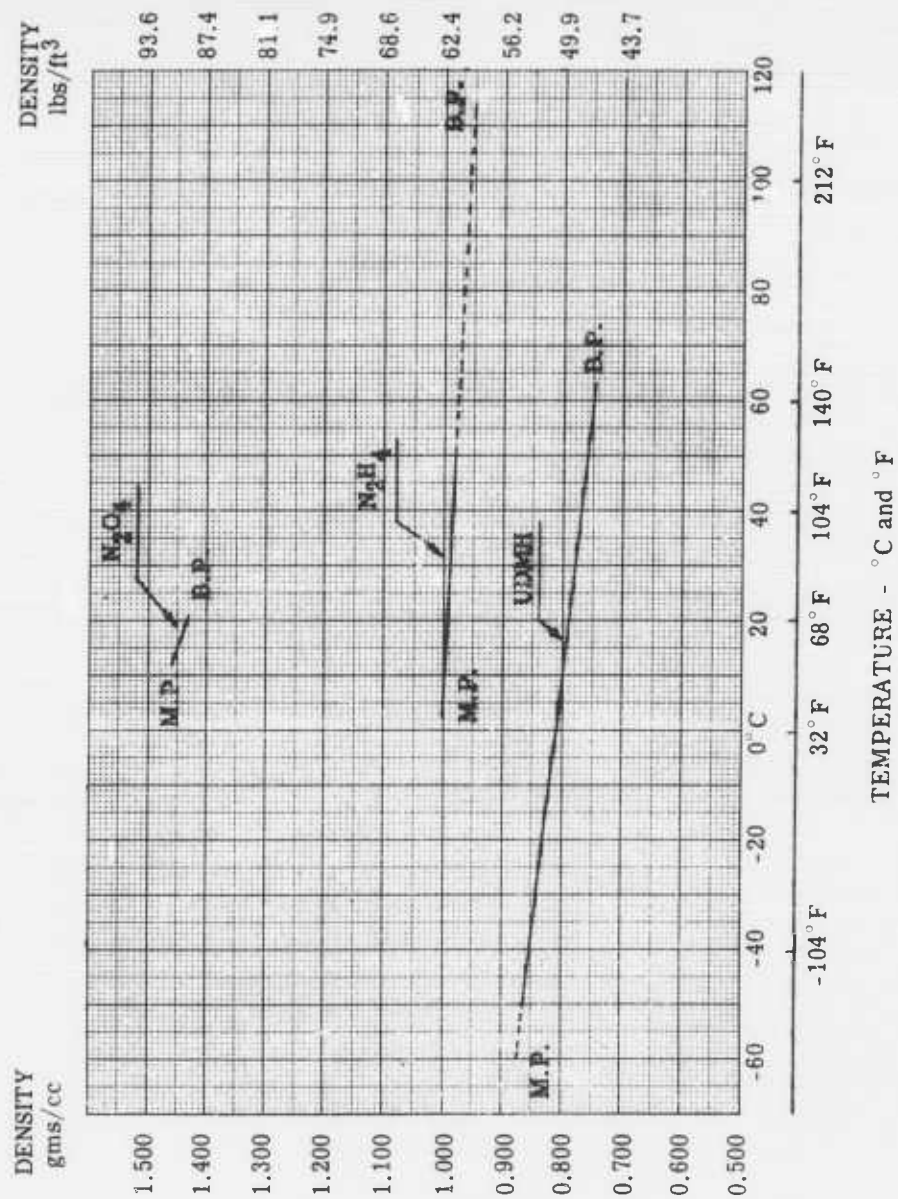
Figure 16. Liquid Phase Properties
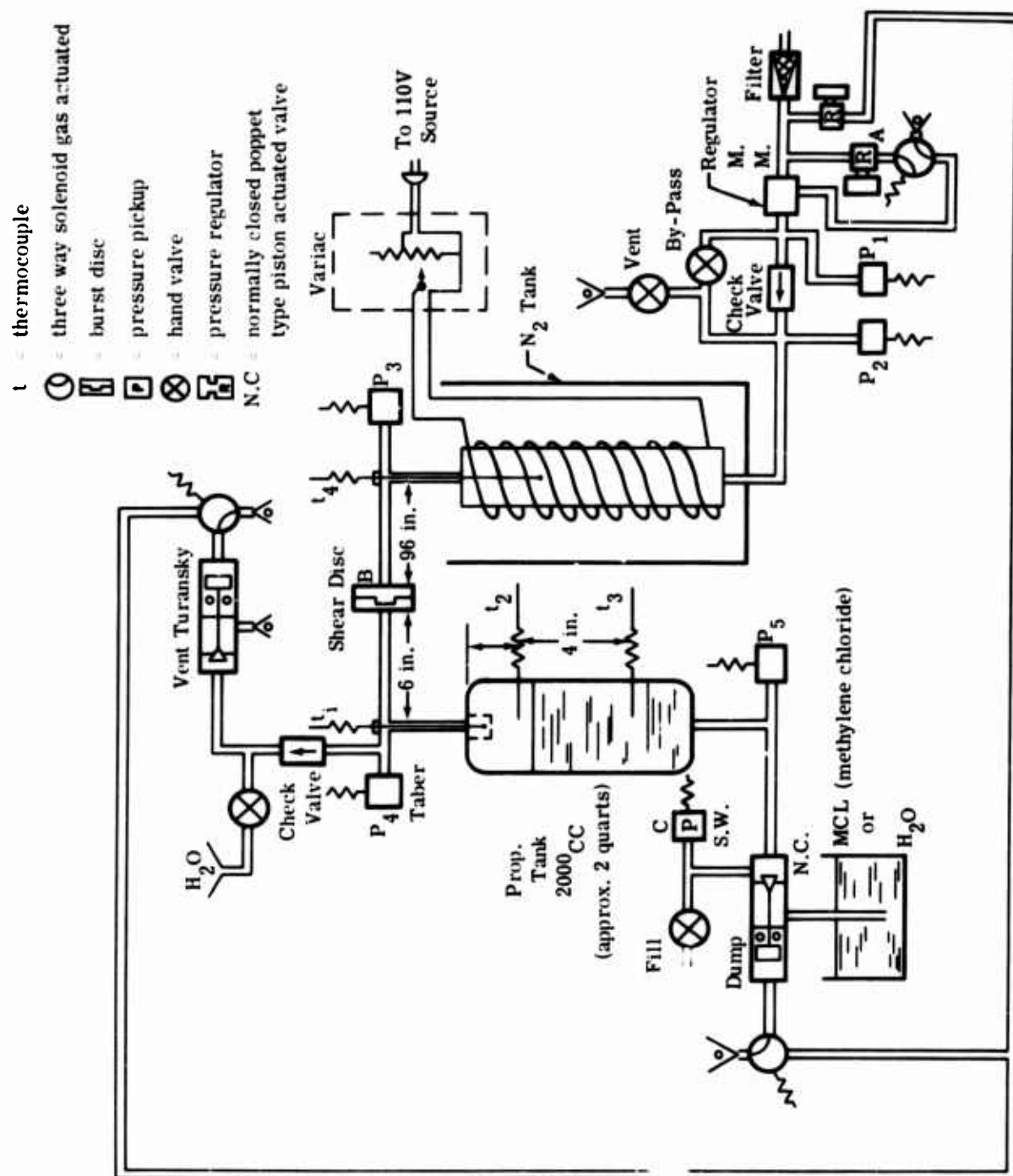
Figure 17. Propellant Expulsion Test Schematic
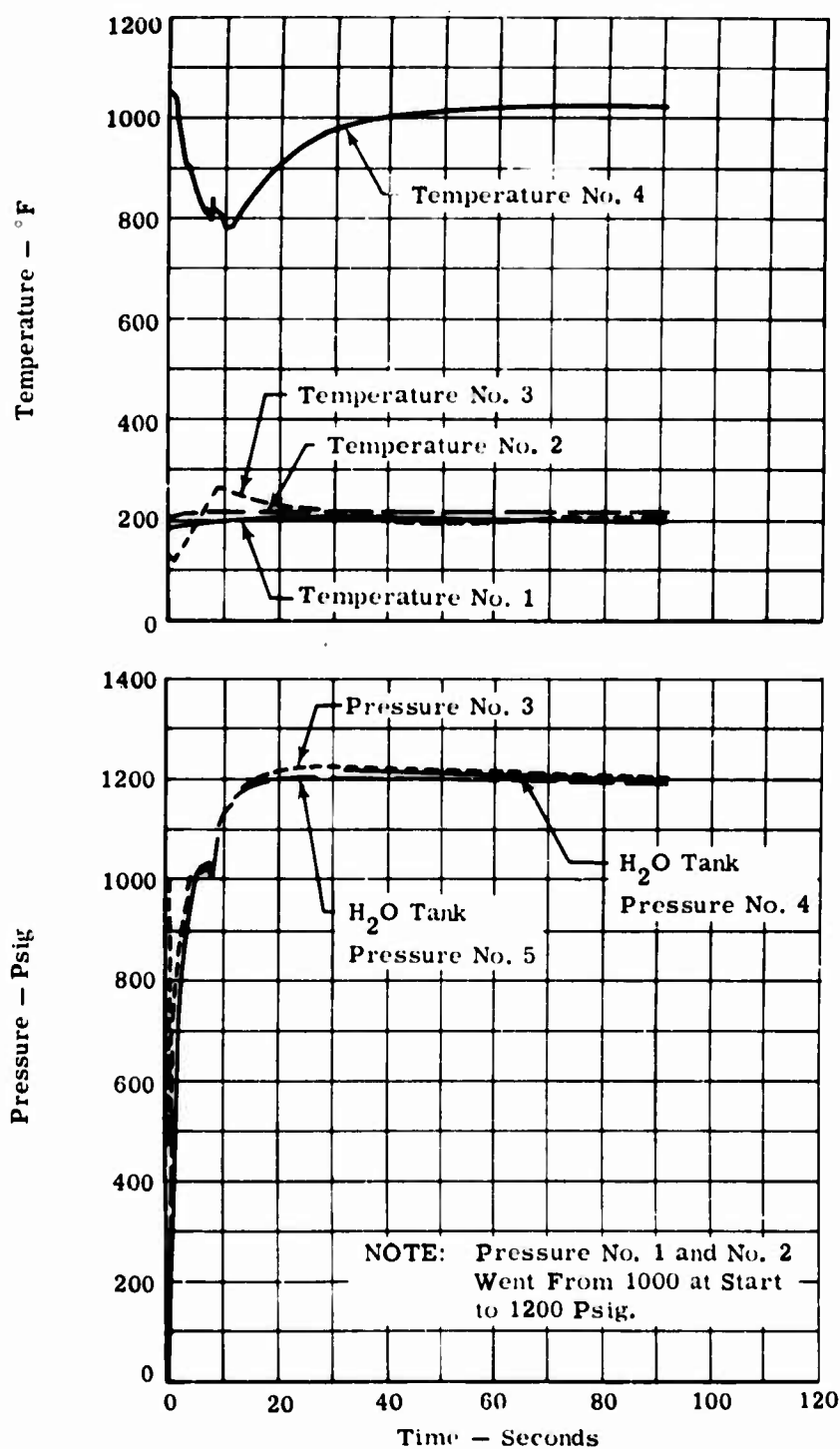
Figure 18. Gas Pressurization Test - H_2O at 200° F
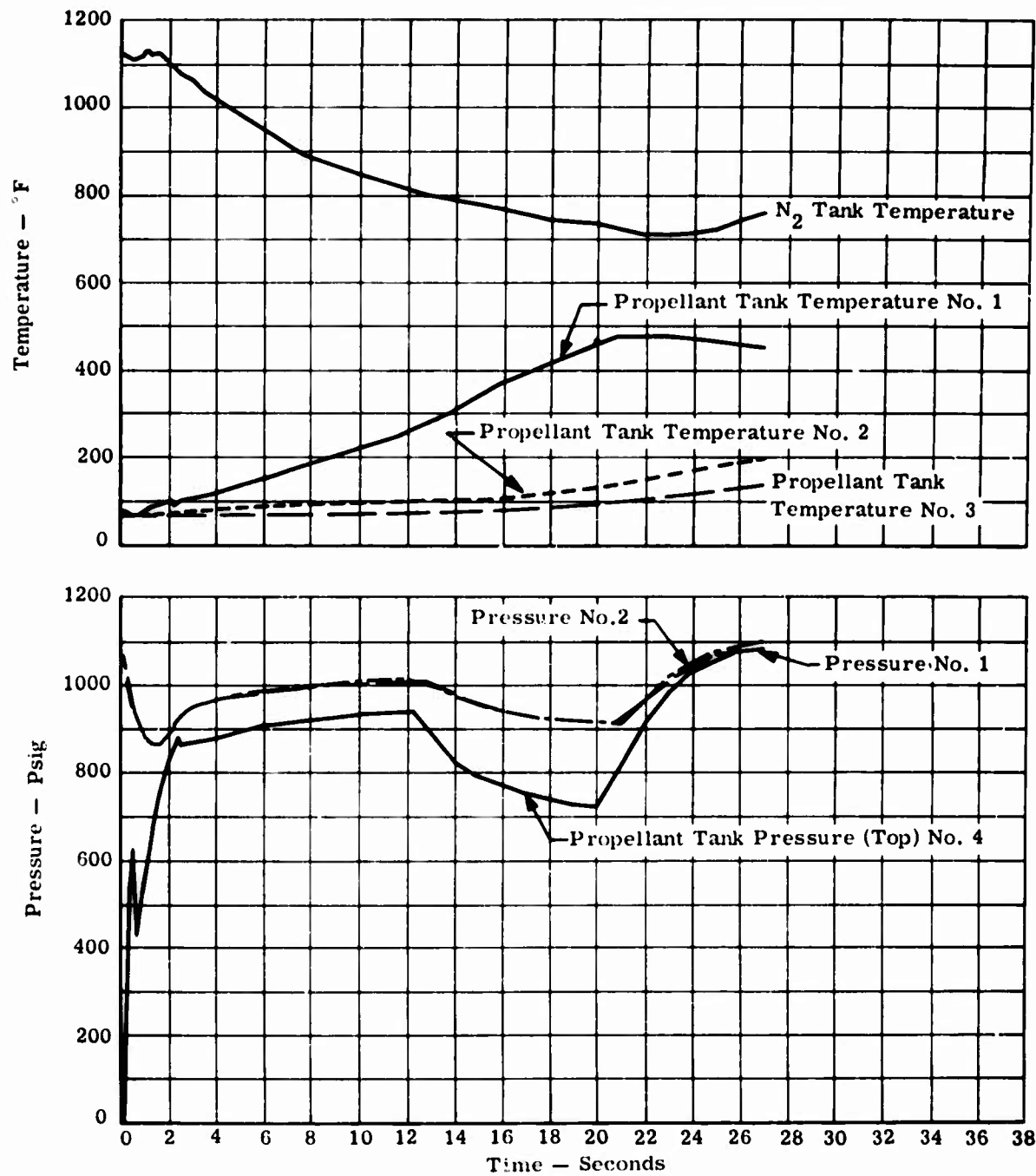
Figure 19. Gas Pressurization Test - N_2O_4 at 70°F
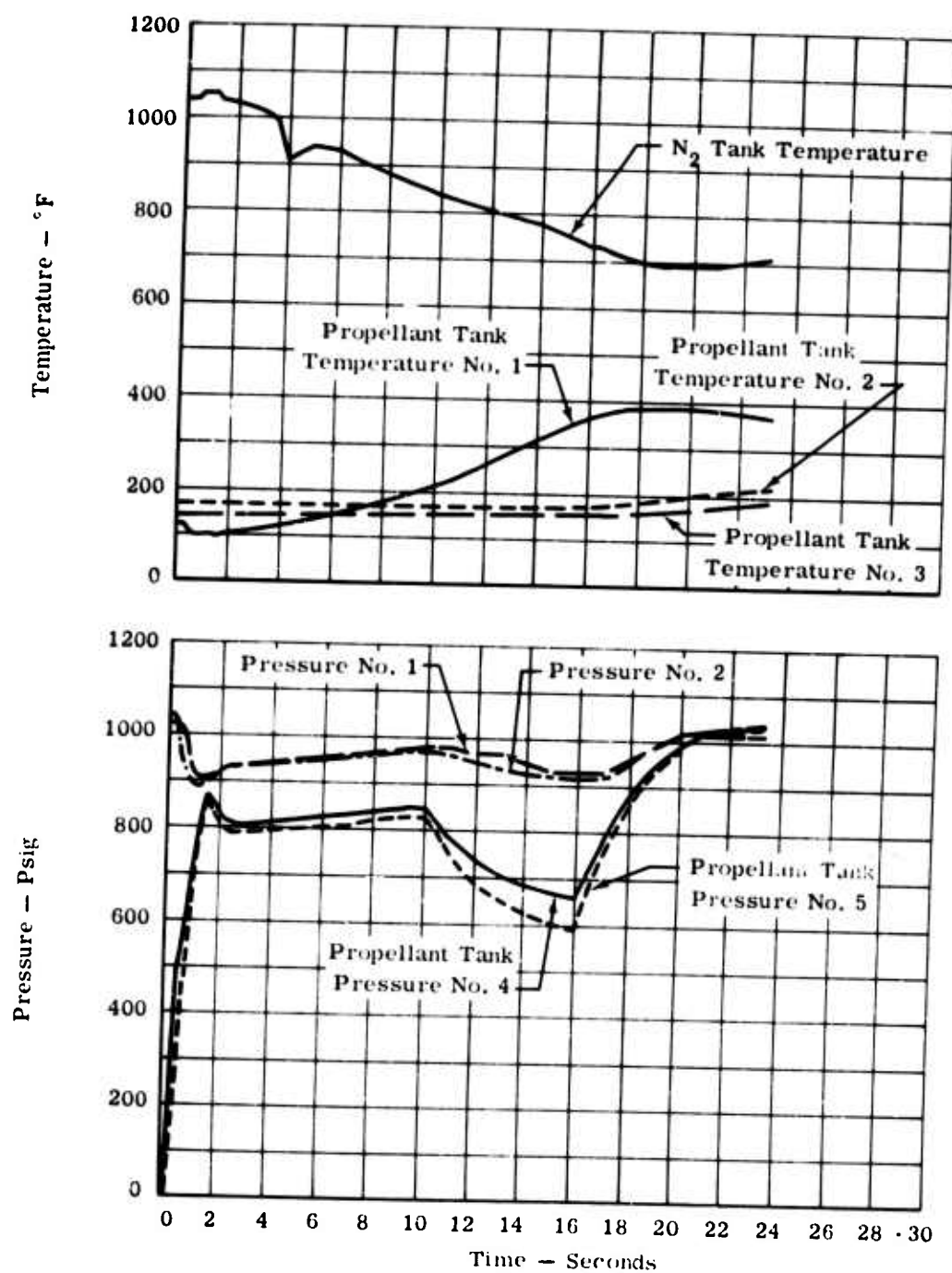
Figure 20. Gas Pressurization Test-UDMH at 140°F
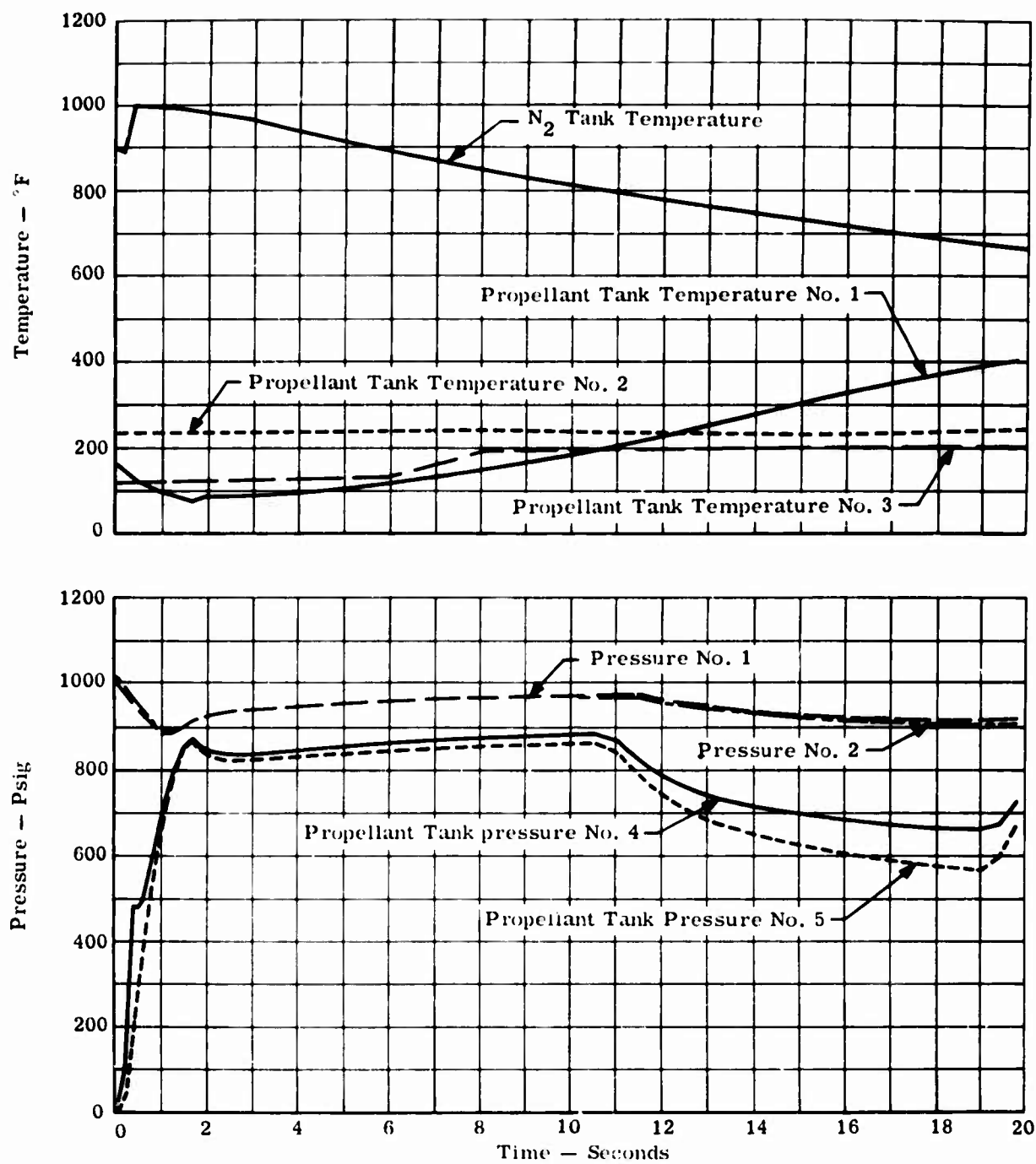
Figure 21. Gas Pressurization Test - N_2H_4 at 170° F
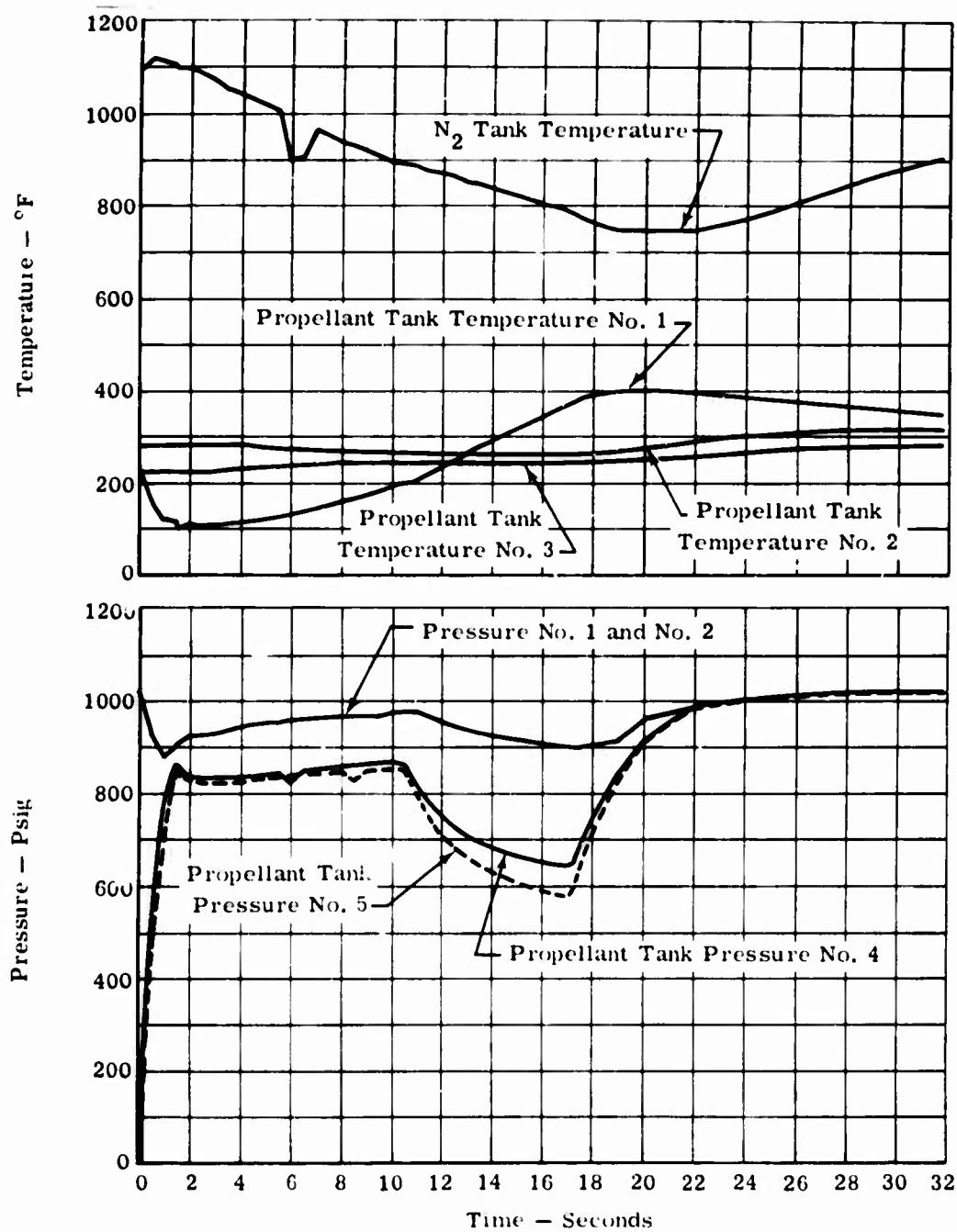
Figure 22. Gas Pressurization Test - N_2H_4 at 223 F
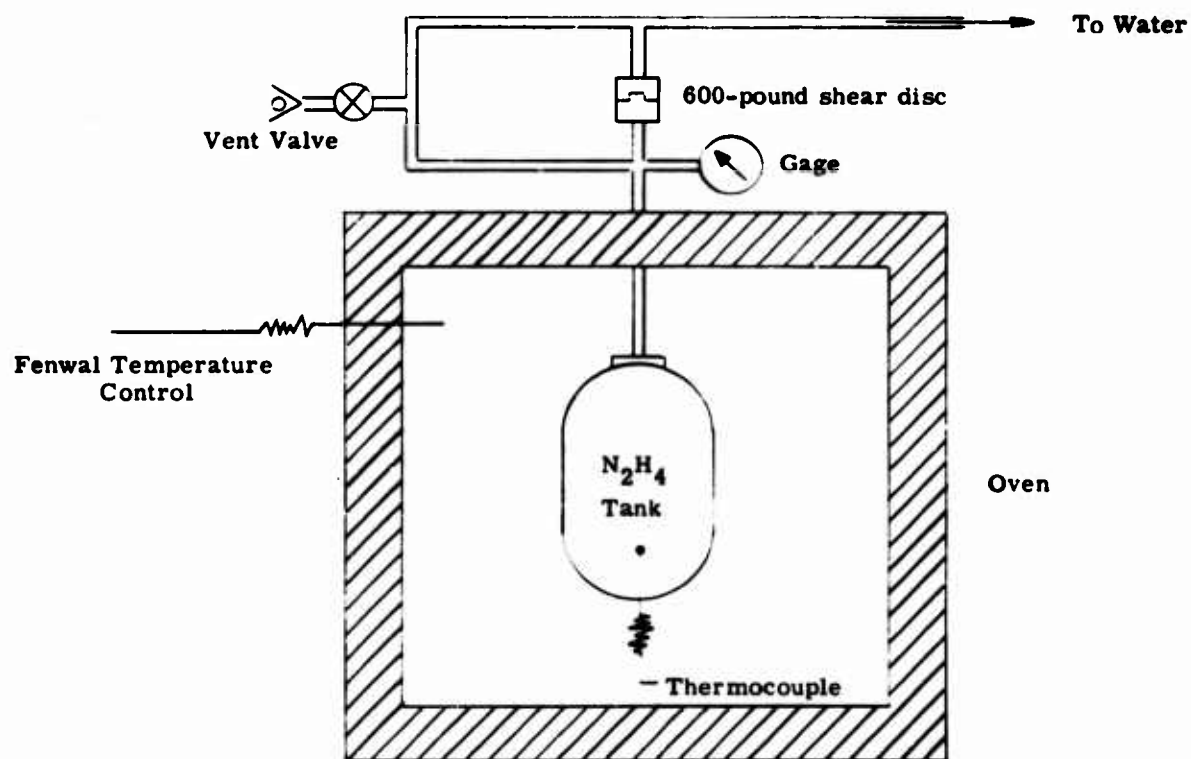
Figure 23. Schematic of Typical Tank Installation in Oven
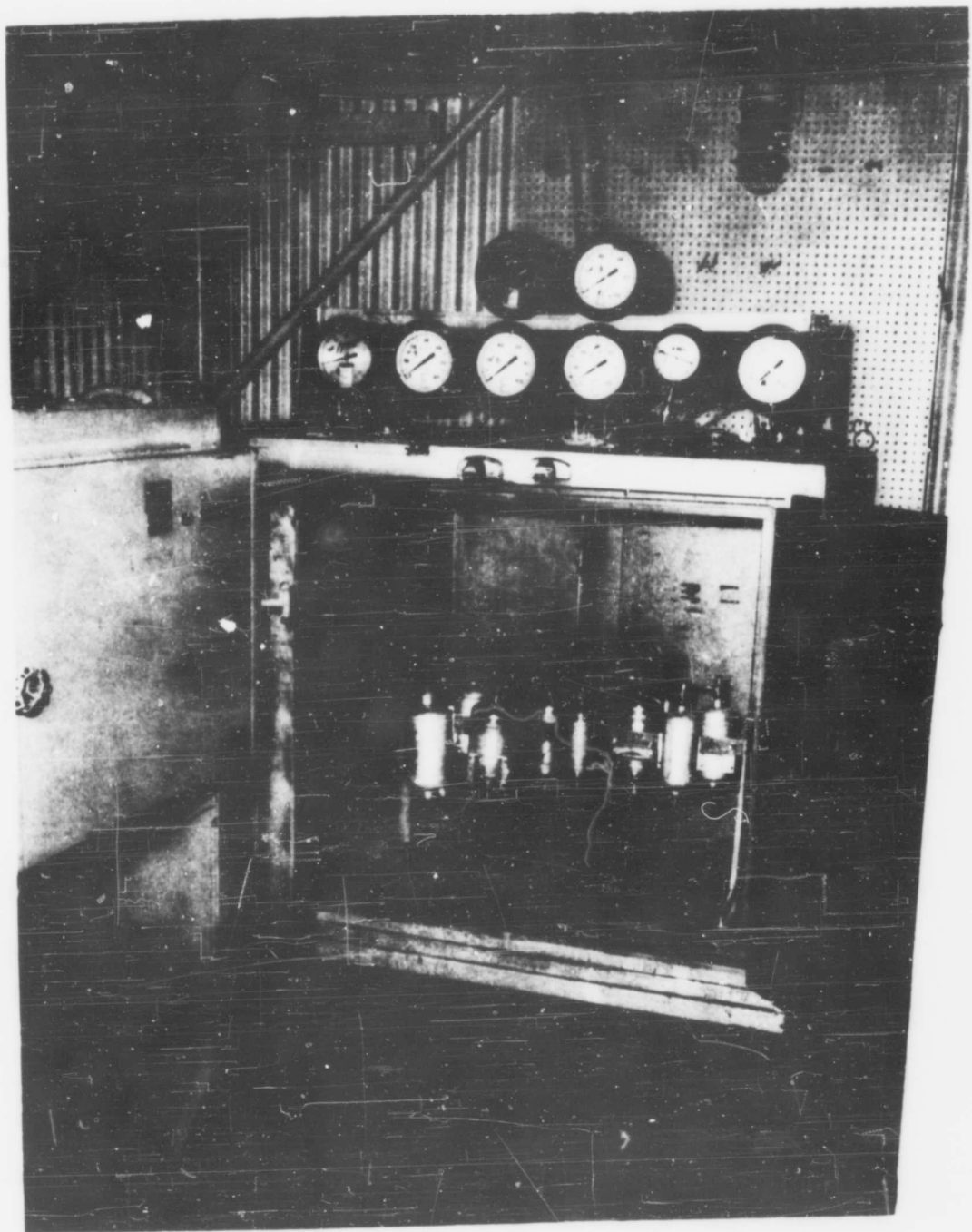
Figure 24. UDMH, N_2H_4 Temperature Limits (300° F) Test Set-up - Run 1
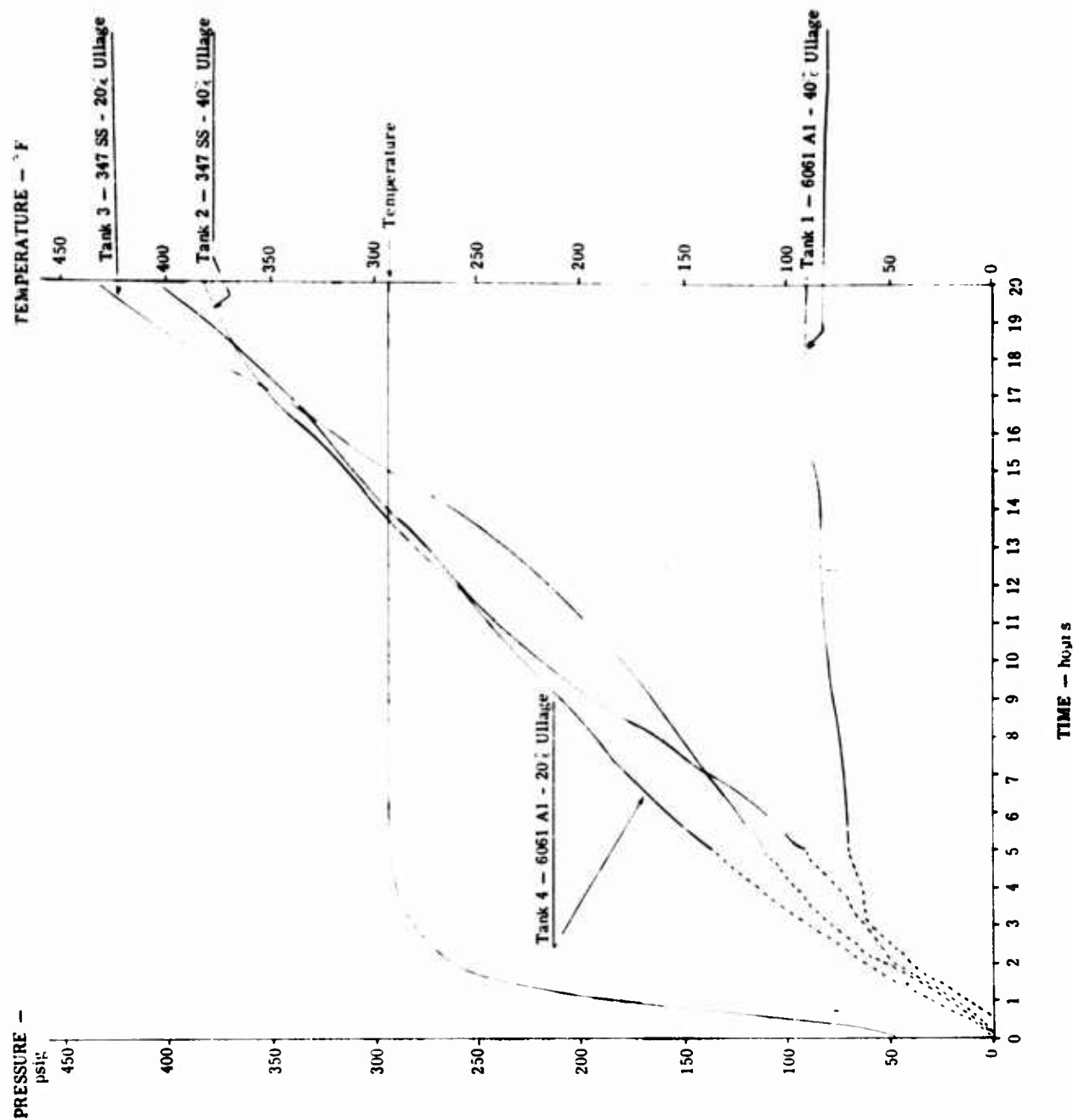
Figure 25. Pressure vs Time Curves - N_2H_4 Temperature Limits Test - Run 1
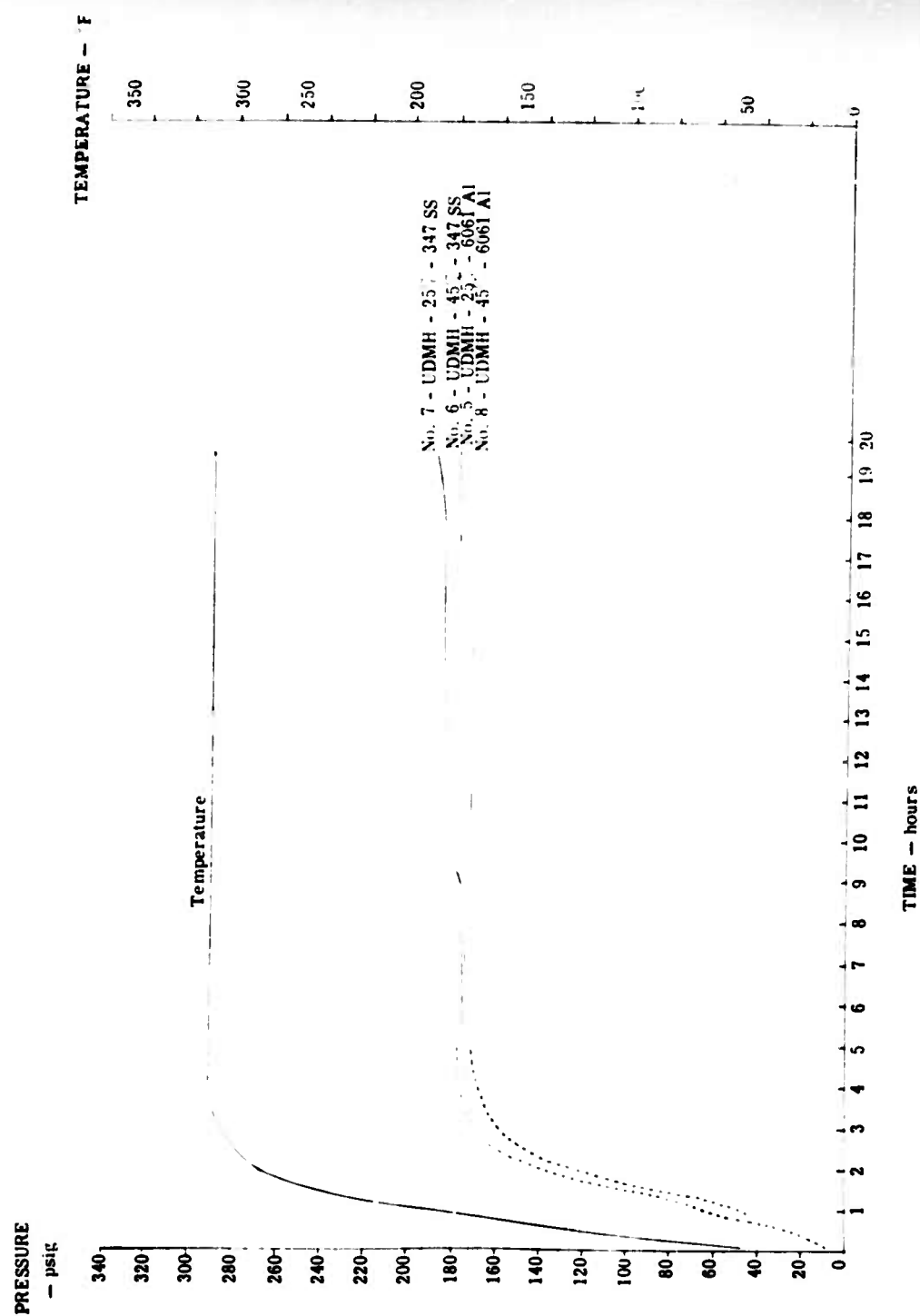
Figure 26. Pressure vs Time Curves - UDMH Temperature
Limits Test - Run 1
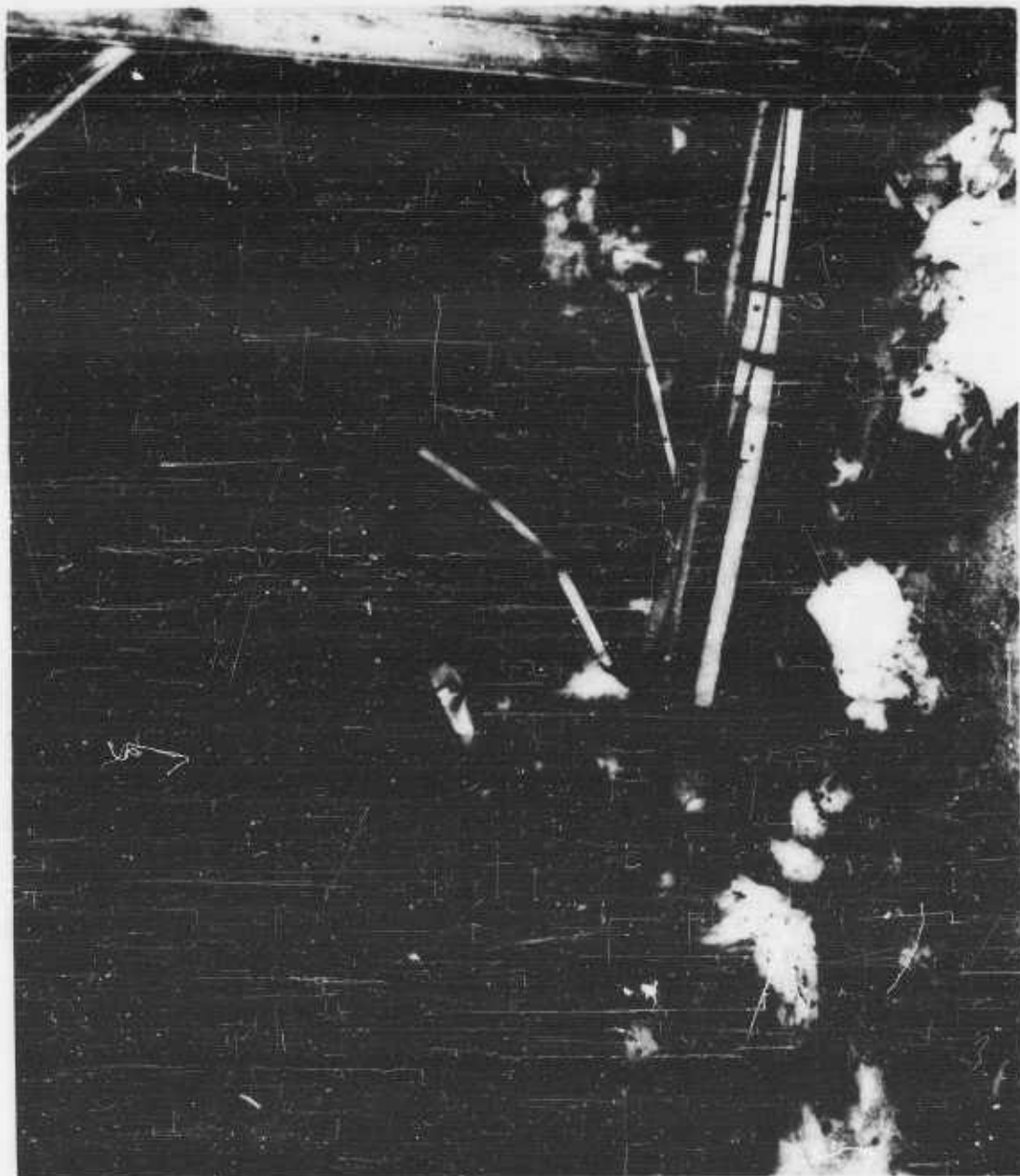
Figure 27. Temperature Limits Test - Explosion Damage to Building
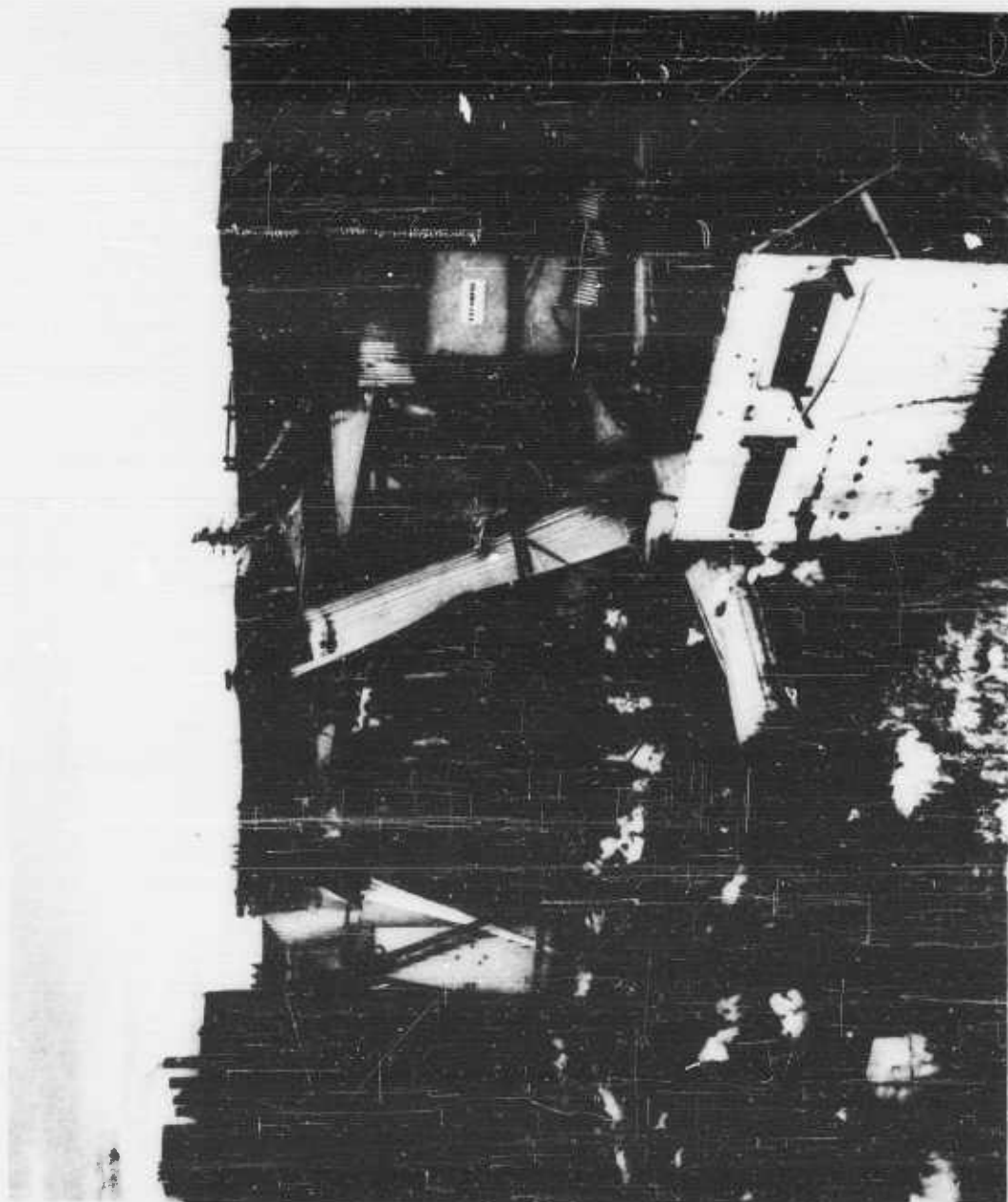
Figure 28. Temperature Limits Test - Explosion Damage to Oven and Hardware
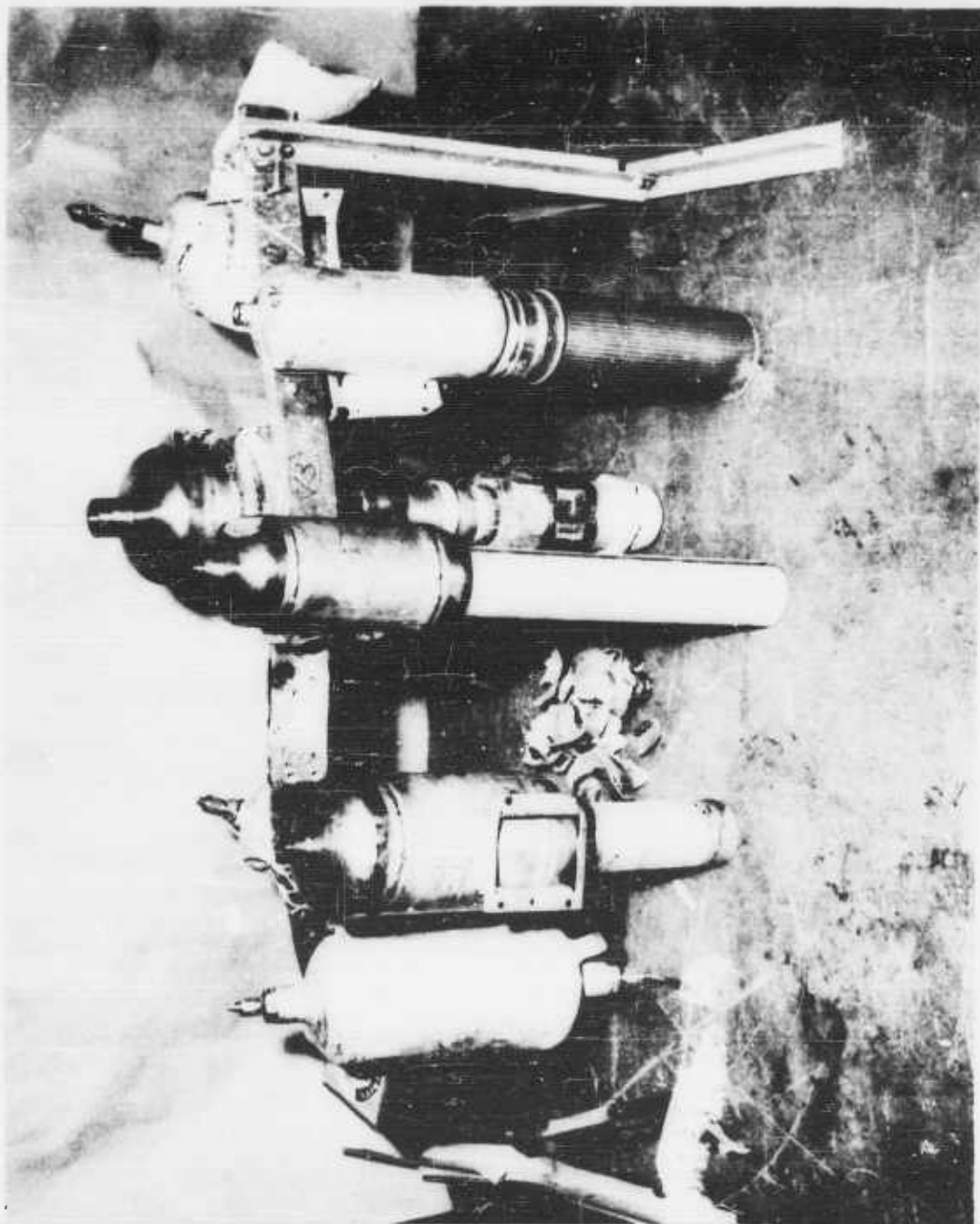
Figure 29. Temperature Limits Test - Explosion Damage to Tanks
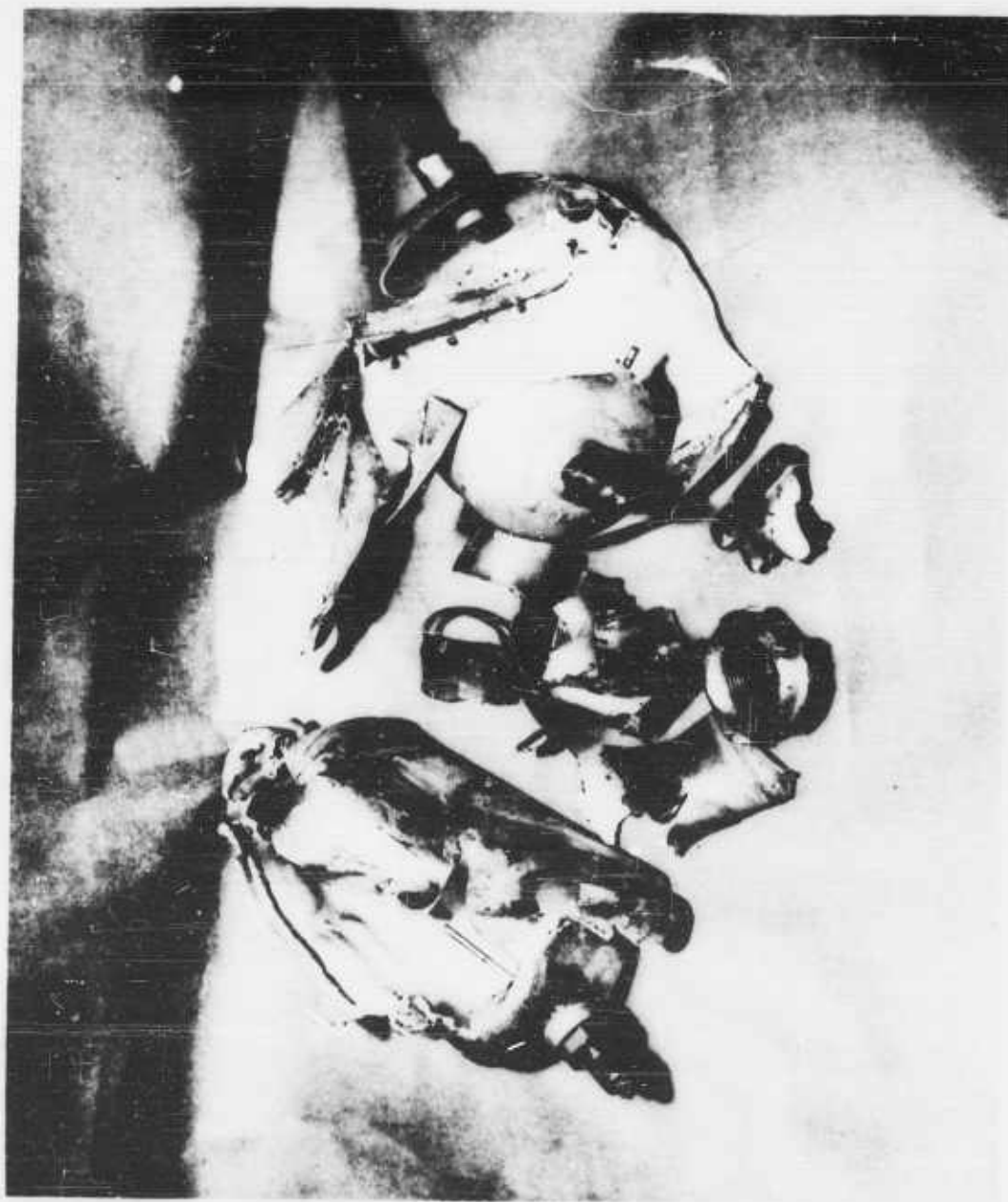
Figure 30. Temperature Limits Test - Explosion Damage to Tanks 1, 2, and 4, from Left to Right
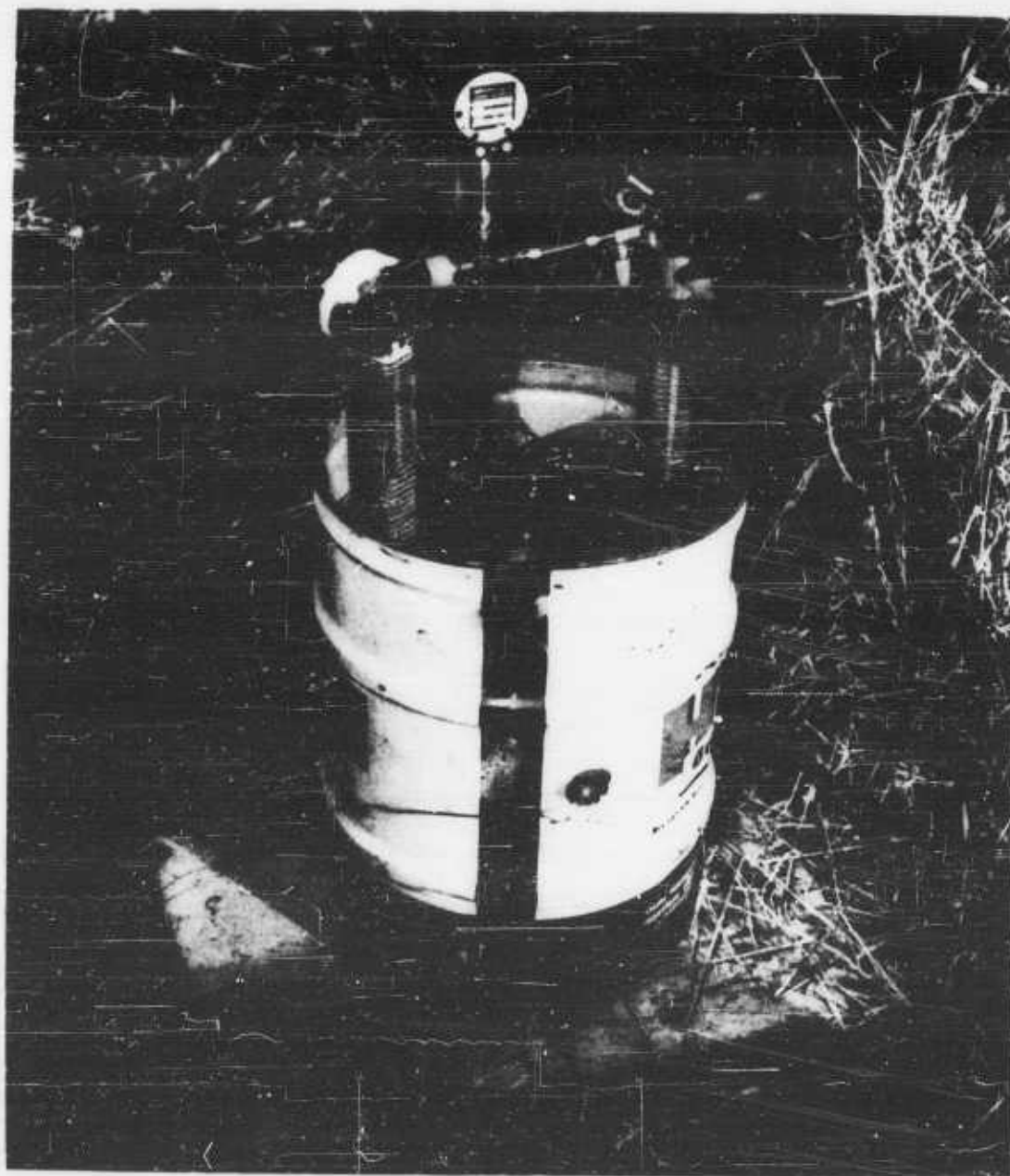
Figure 31. Outdoor Temperature Limits Test with N_2H_4
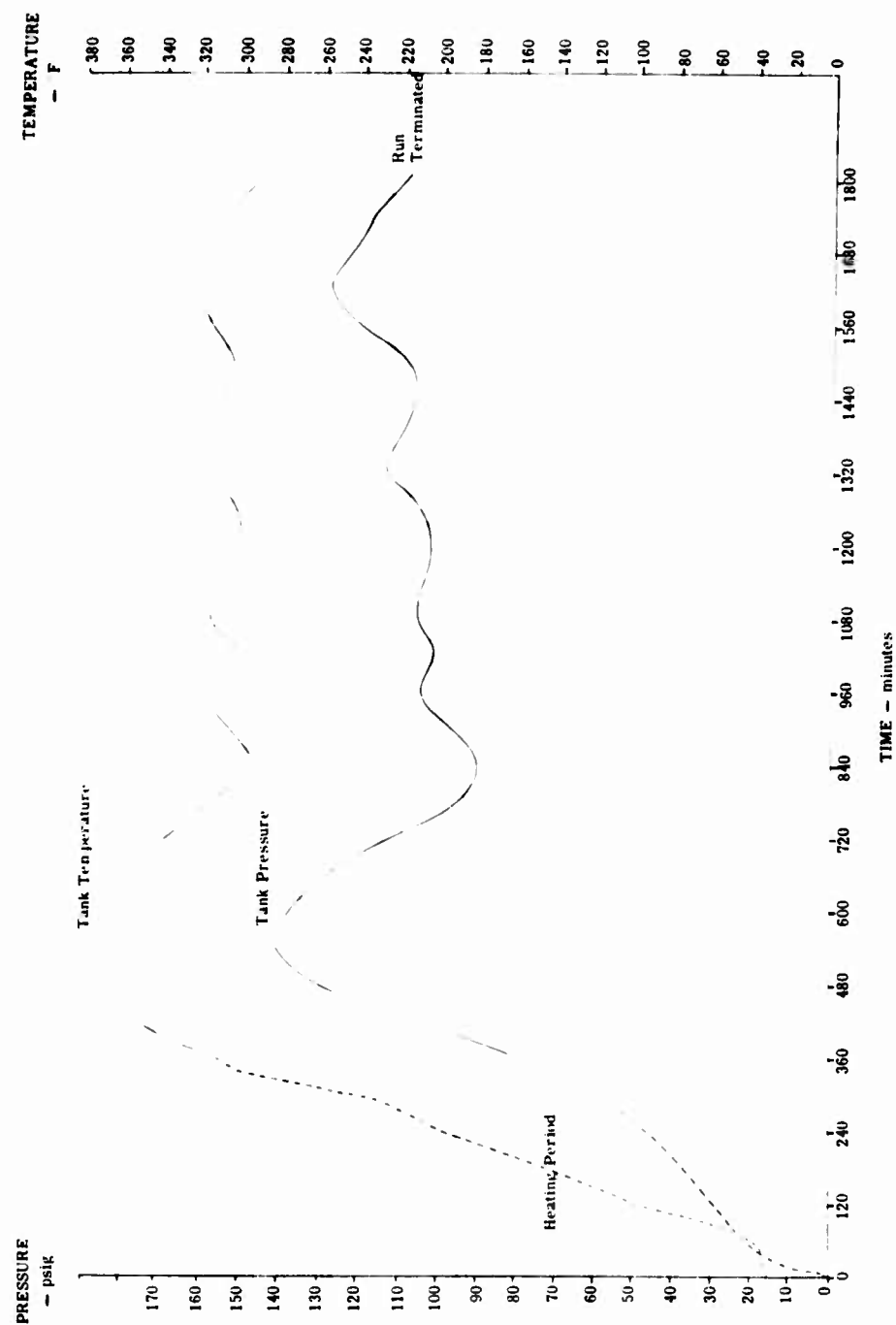
Figure 32. Temperature and Pressure vs Time Curves — N_2H_4 Temperature Limits Test — Run 2

PRESSURE
– psig

TEMPERATURE
– °F

RUN DATES: 12/14/59
12/15/59
12/16/59

Temperature Curves

12/15/59

12/16/59

12/14/59

Pressure Curves

12/15/59

12/16/59

12/14/59

LEGEND

– – – Heating Period
+ + + Recorders Off

TIME – hours
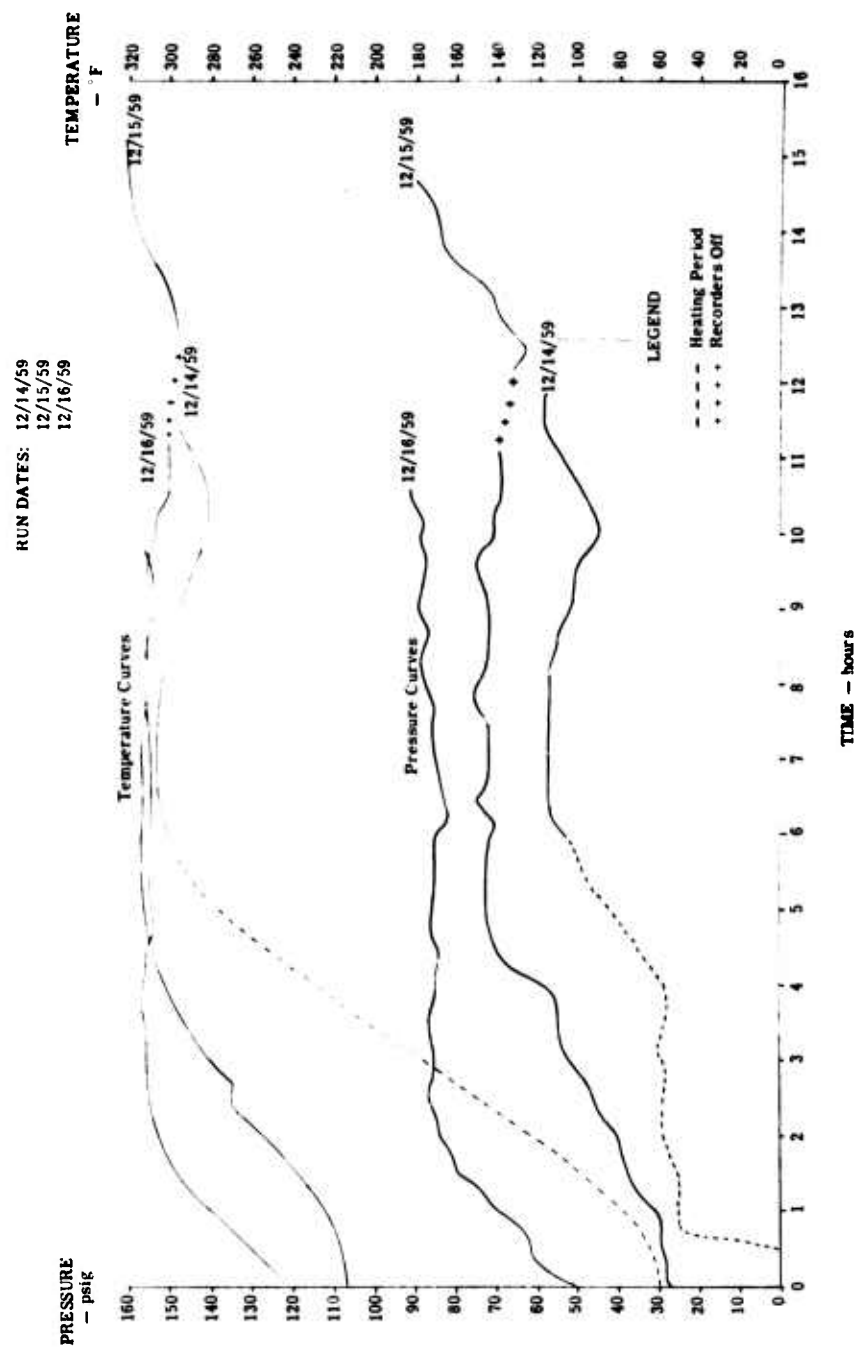
Figure 33. Temperature and Pressure vs Time Curves – N_2H_4 Temperature Limits Test – Run 3
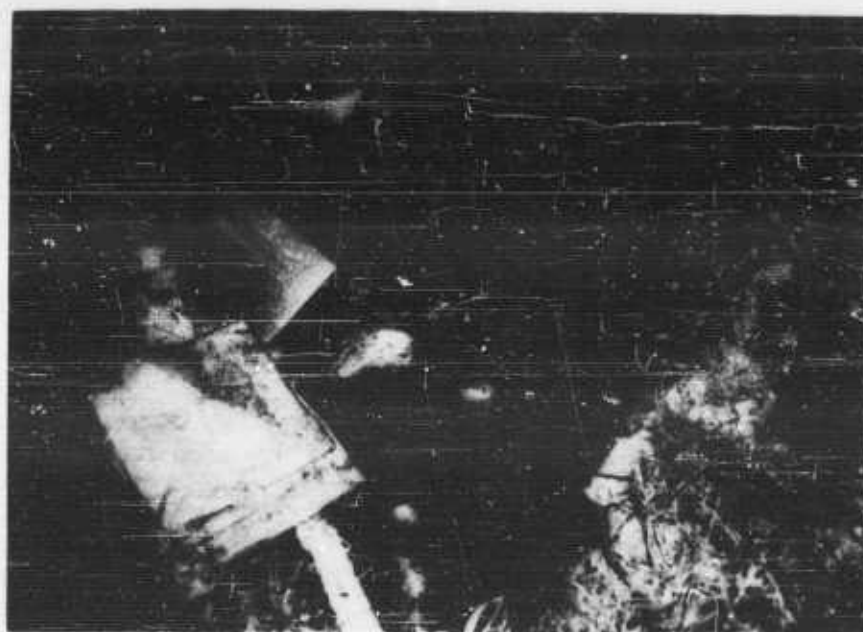
Figure 34 N_2H_4 300°F 24-Hour Test After Explosion of PH 15-7 Mo Tank

Figure 35. Shrapnel of PH 15-7 Mo Tank
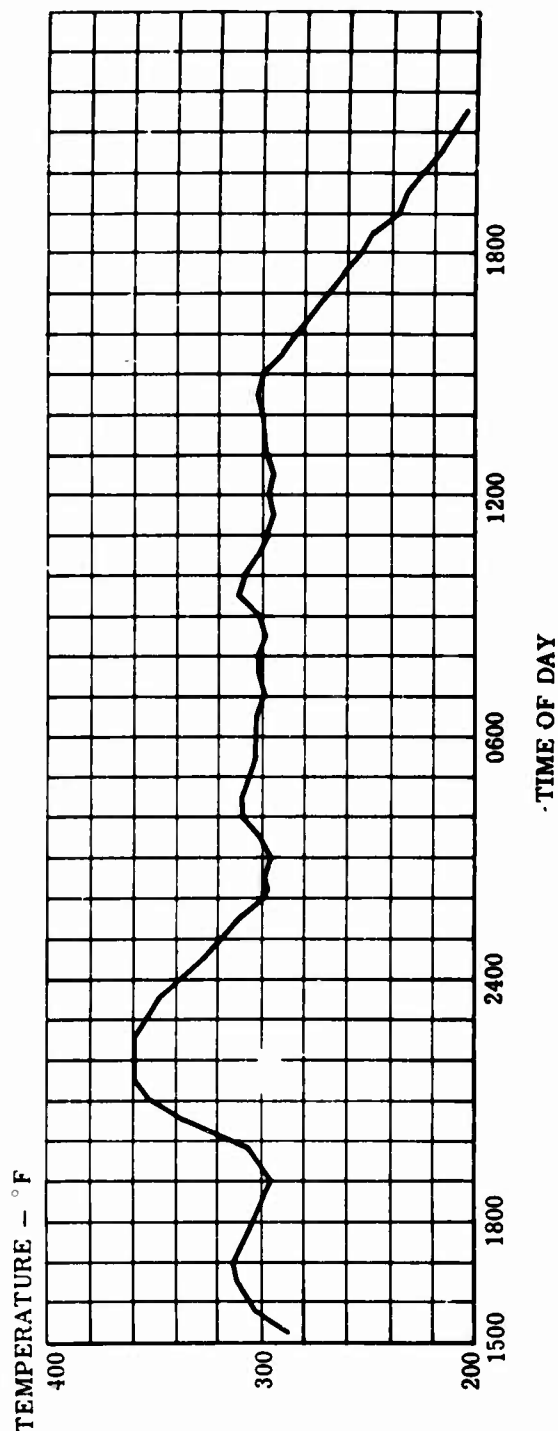
Figure 36. N_2H_4 at 300°F for 24 Hours (Aluminum Benson Tank)

99

Pressure – Psig
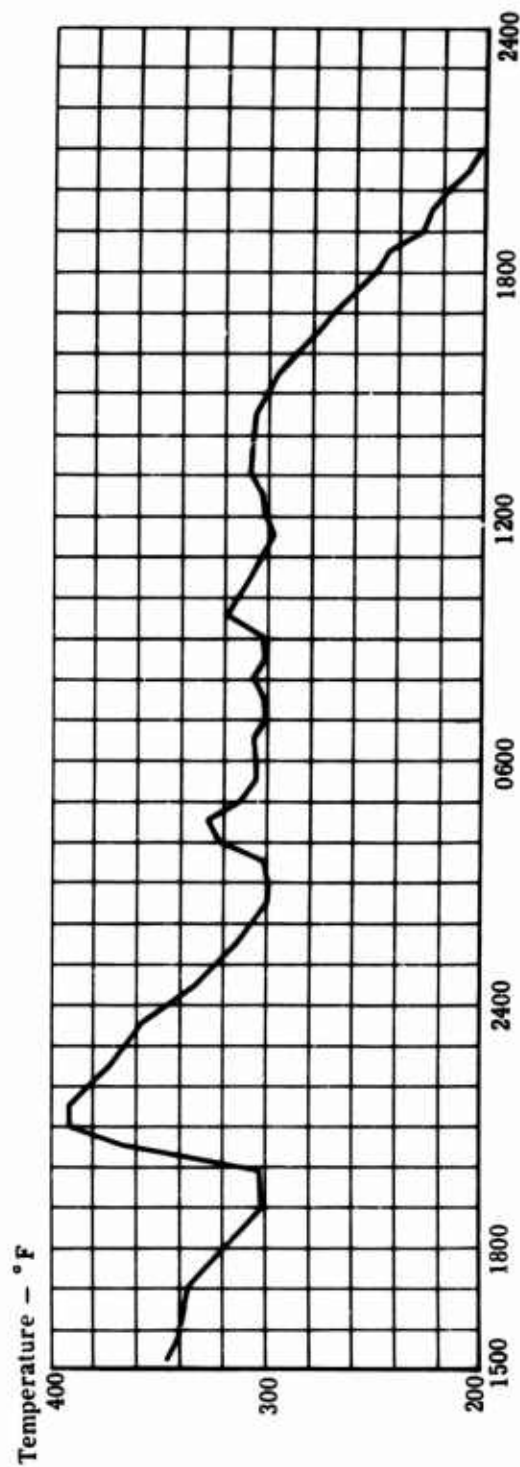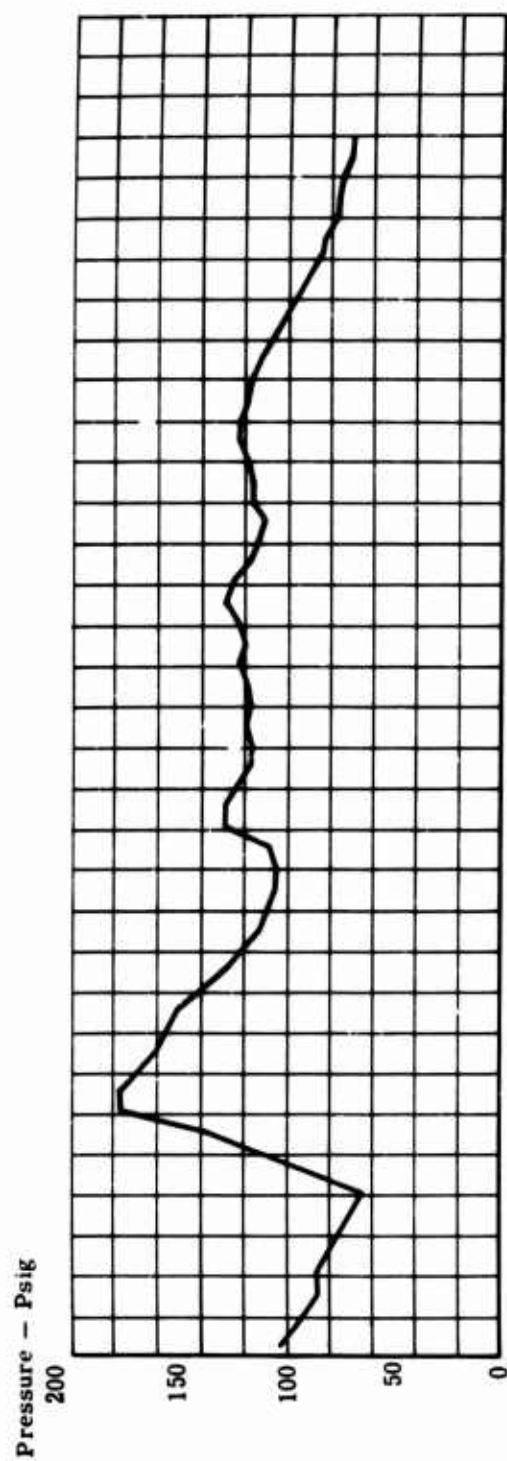
Temperature – °F

Time of Day

Figure 37. N_2H_4 at 300°F (Titanium Benson Tank)
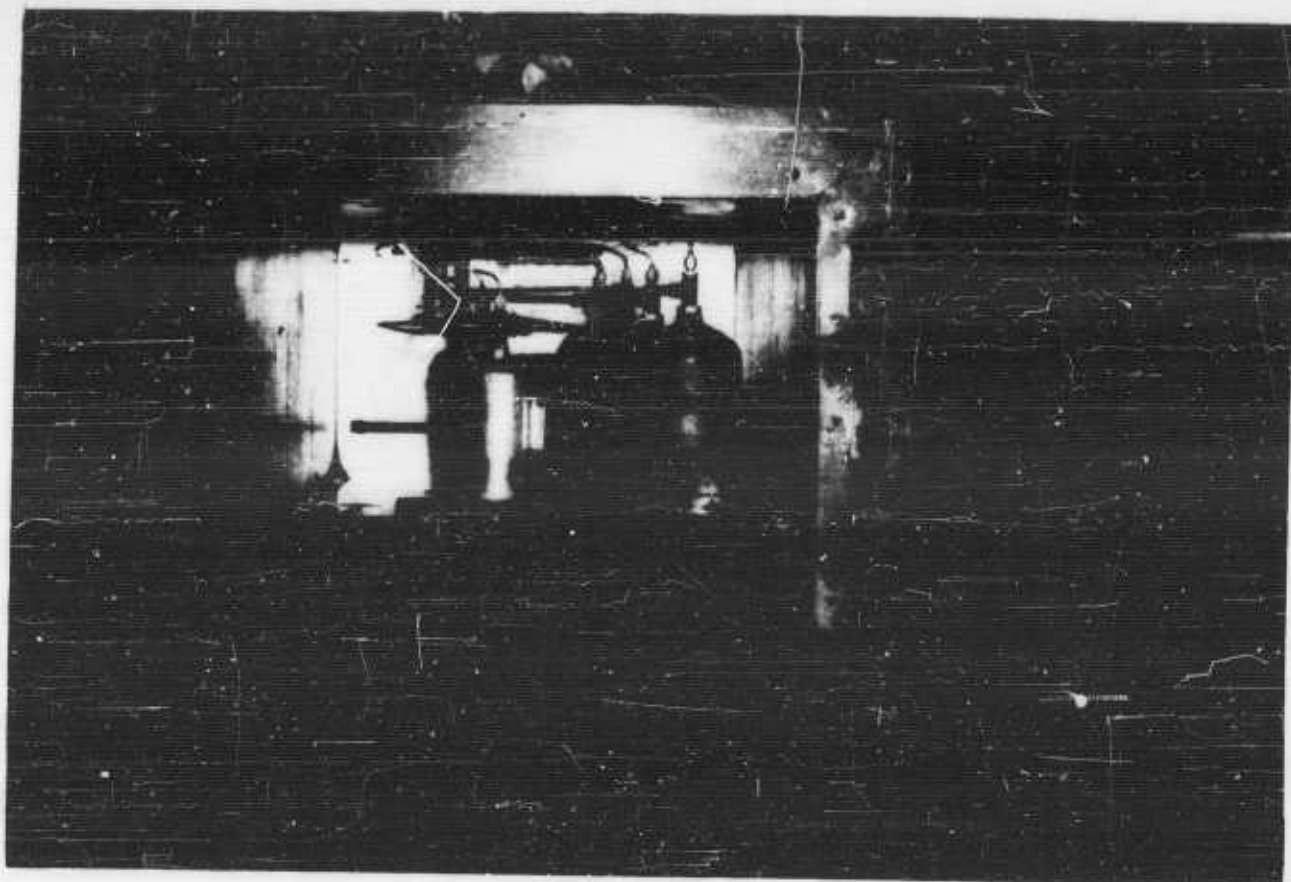
Figure 38. Temperature Limits Test — UDMH Tank Tests at 300° F
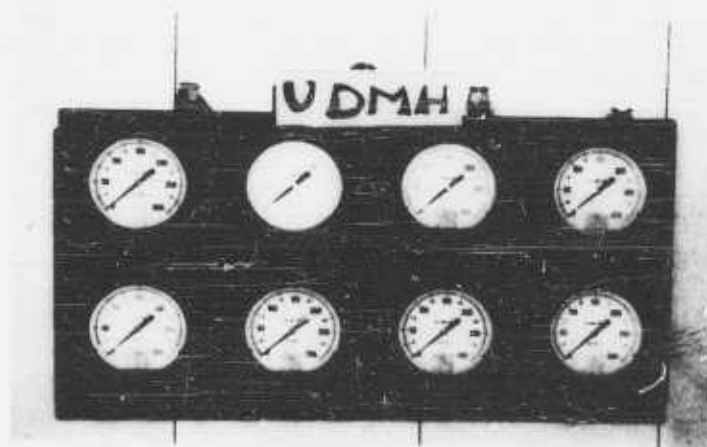
Figure 39. Pressure Gage Panel for 300° UDMH Tank Tests
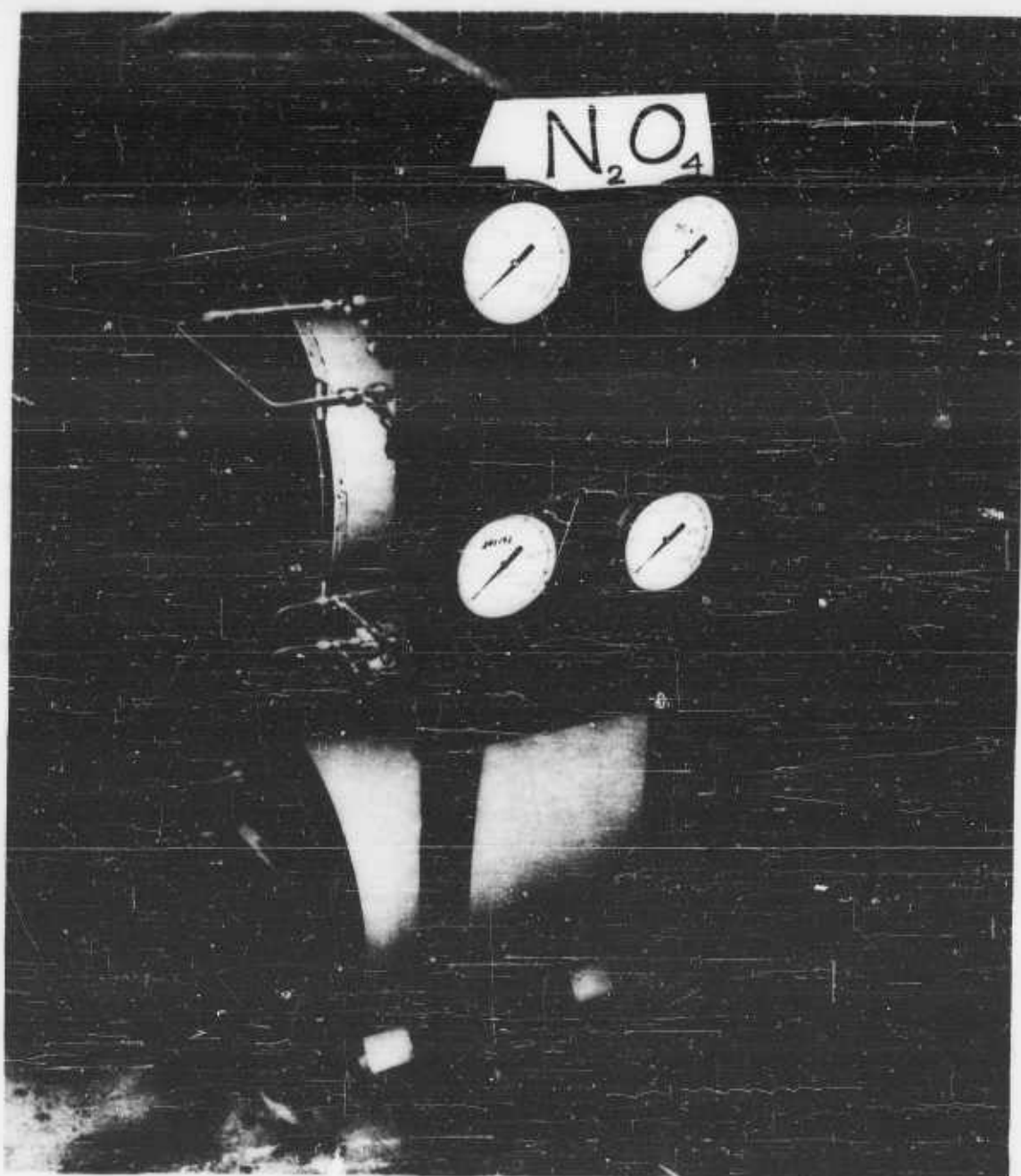
Figure 40. Temperature Limits Test — N_2O_4 Tank Tests at 270°F
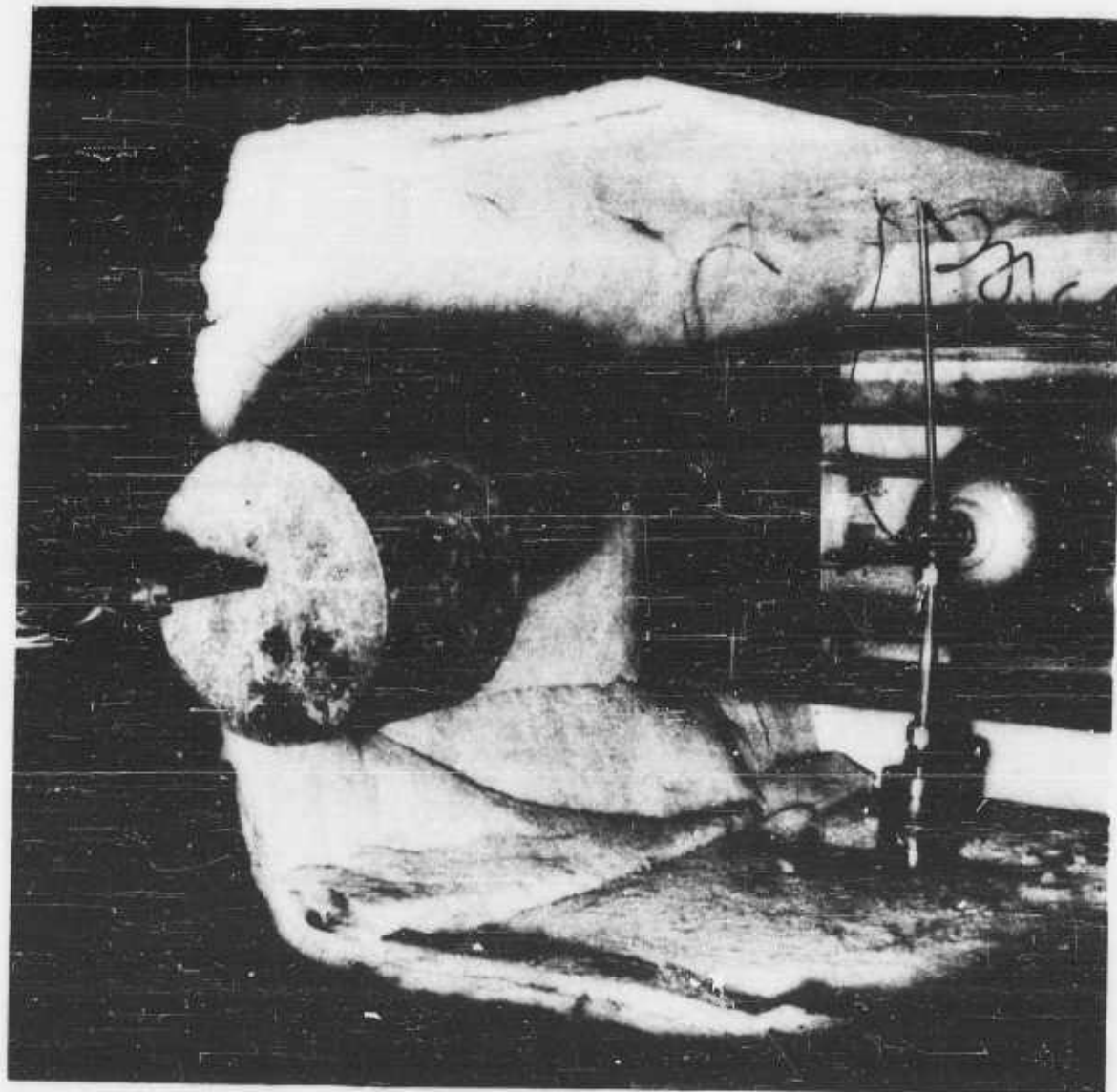
Figure 41. Temperature Limits Test - Test Set-up for High Temperature Tests
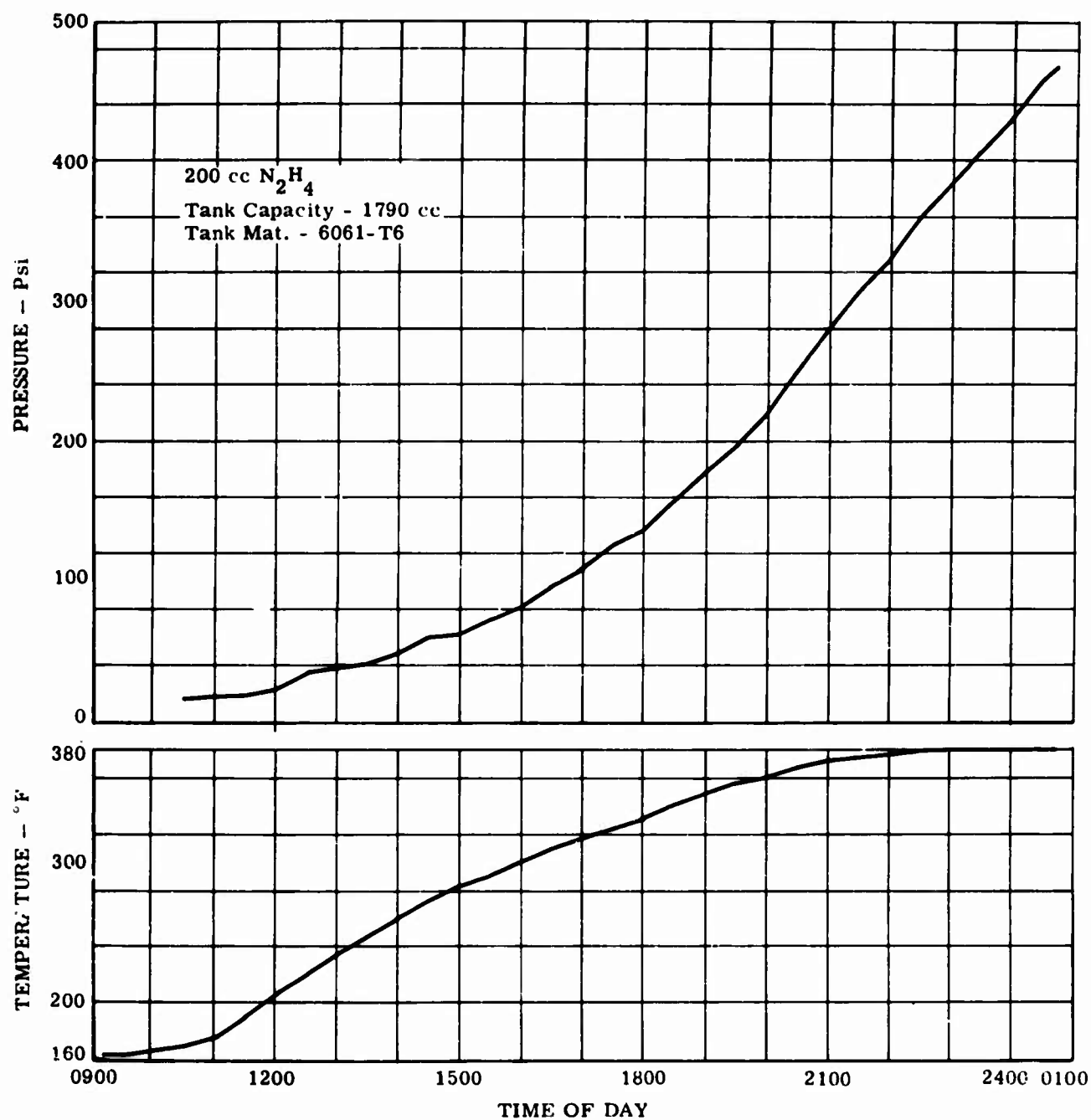
Figure 42. Temperature Limits Tests Above 300°F with N_2H_4 in 6061-T6 Aluminum Tank
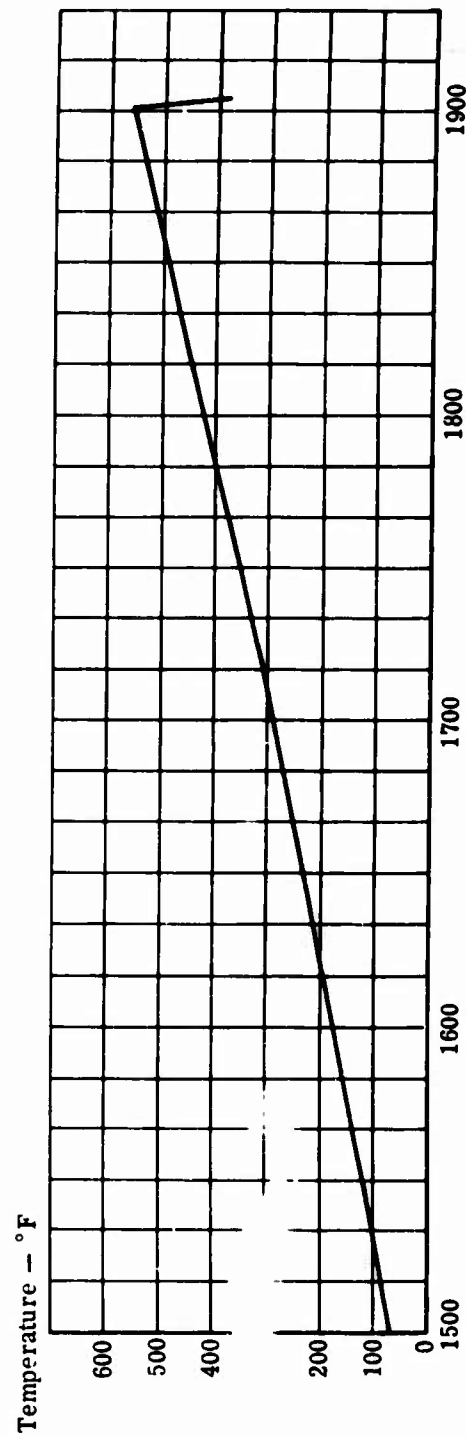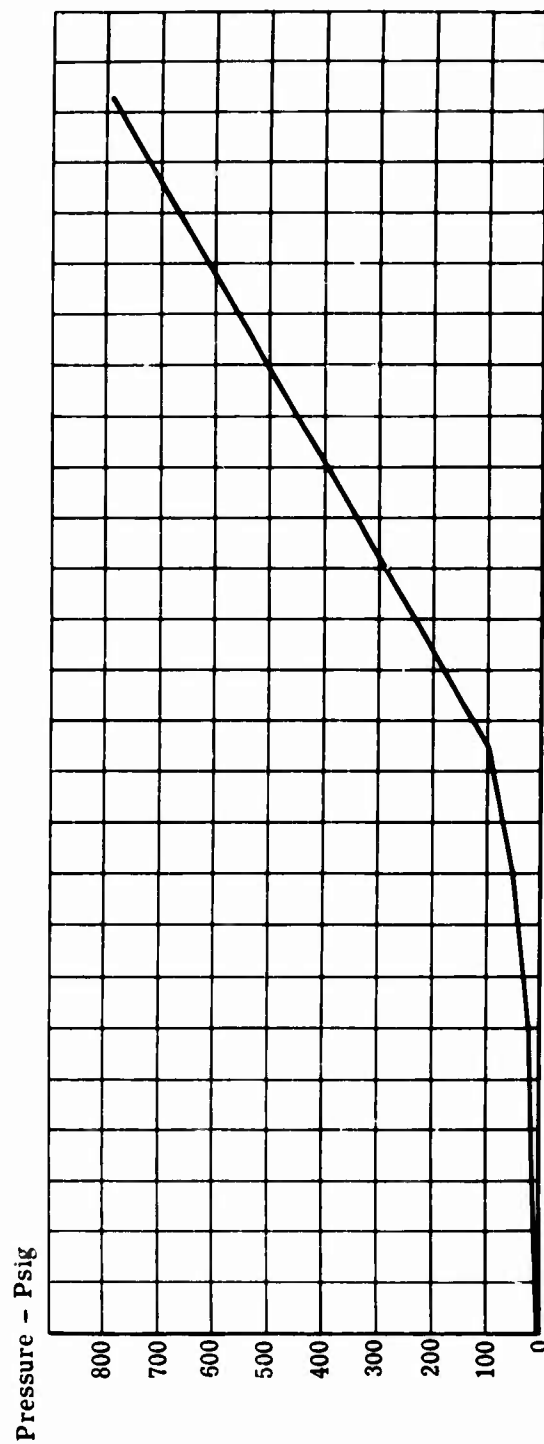
Figure 43. Temperature Limits Test Above 300°F with UDMH in 347 Stainless Steel Tank

Time of Day
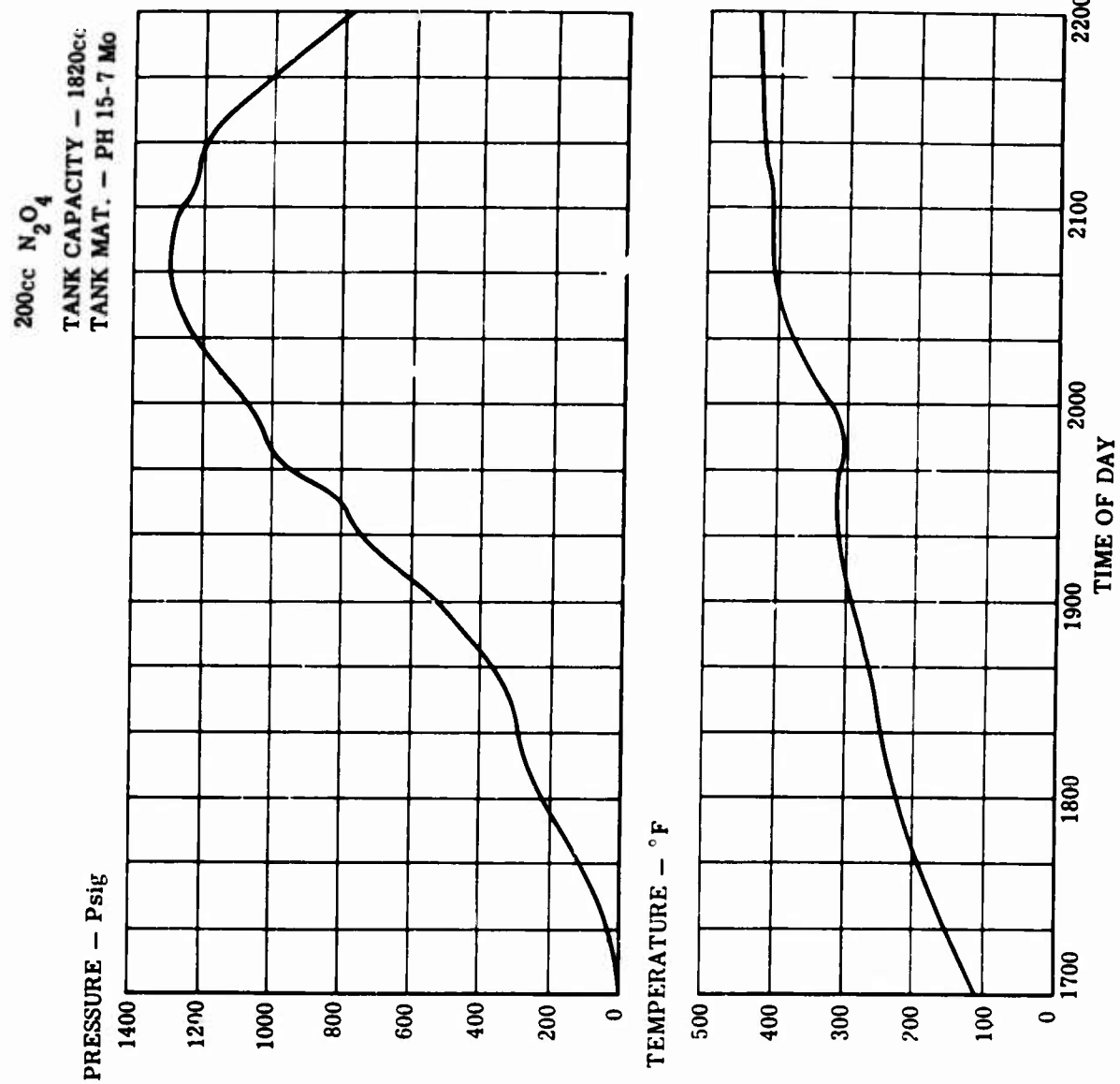
Figure 44. Temperature Limits Test Above 300°F with N_2O_4 in PH 15-7 Mo Tank
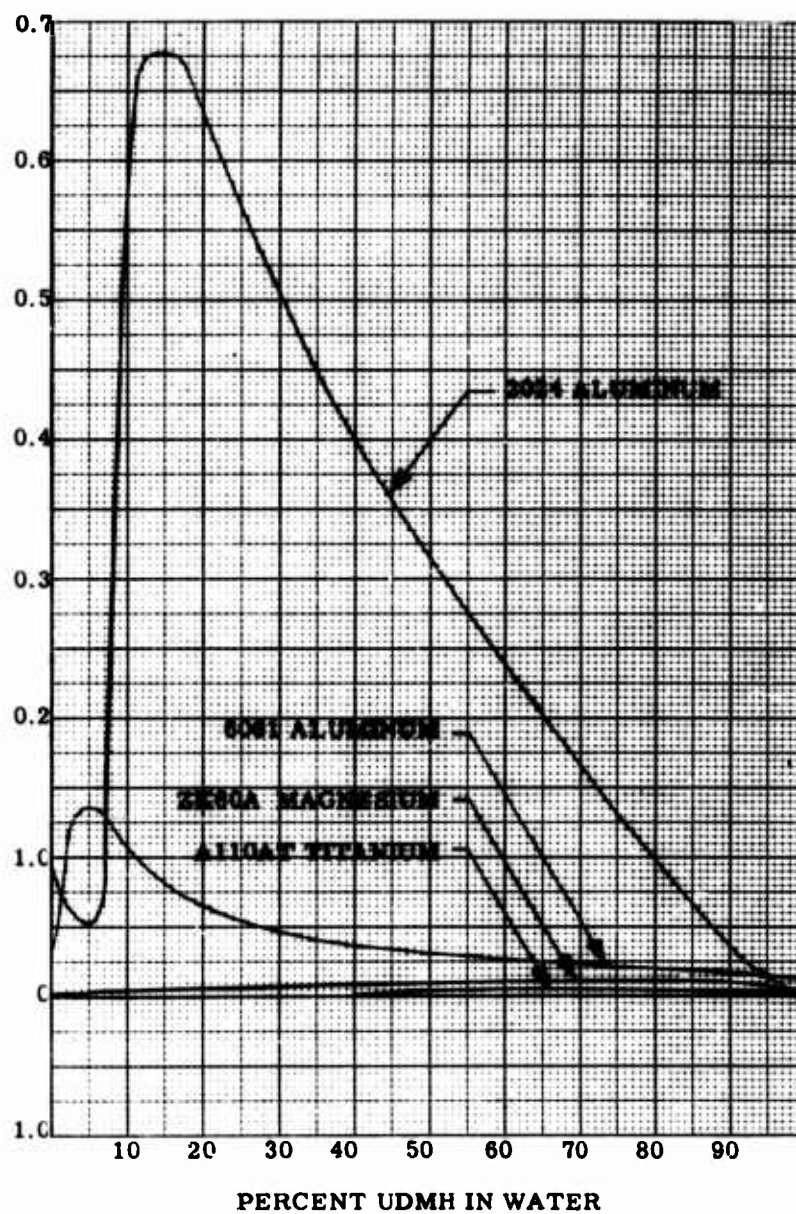
Figure 45. Corrosion Rate of Several Metals in UDMH Solutions
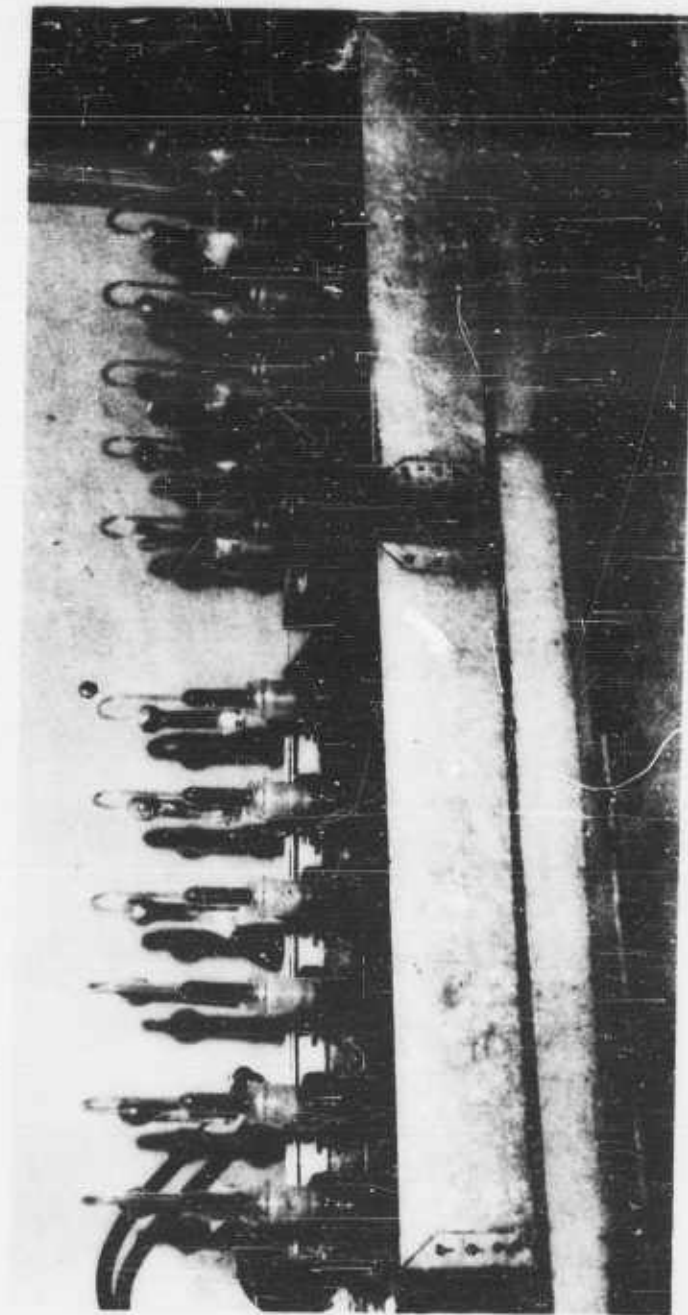
Figure 46. Set Up for N_2O_4 Metal Compatibility Tests
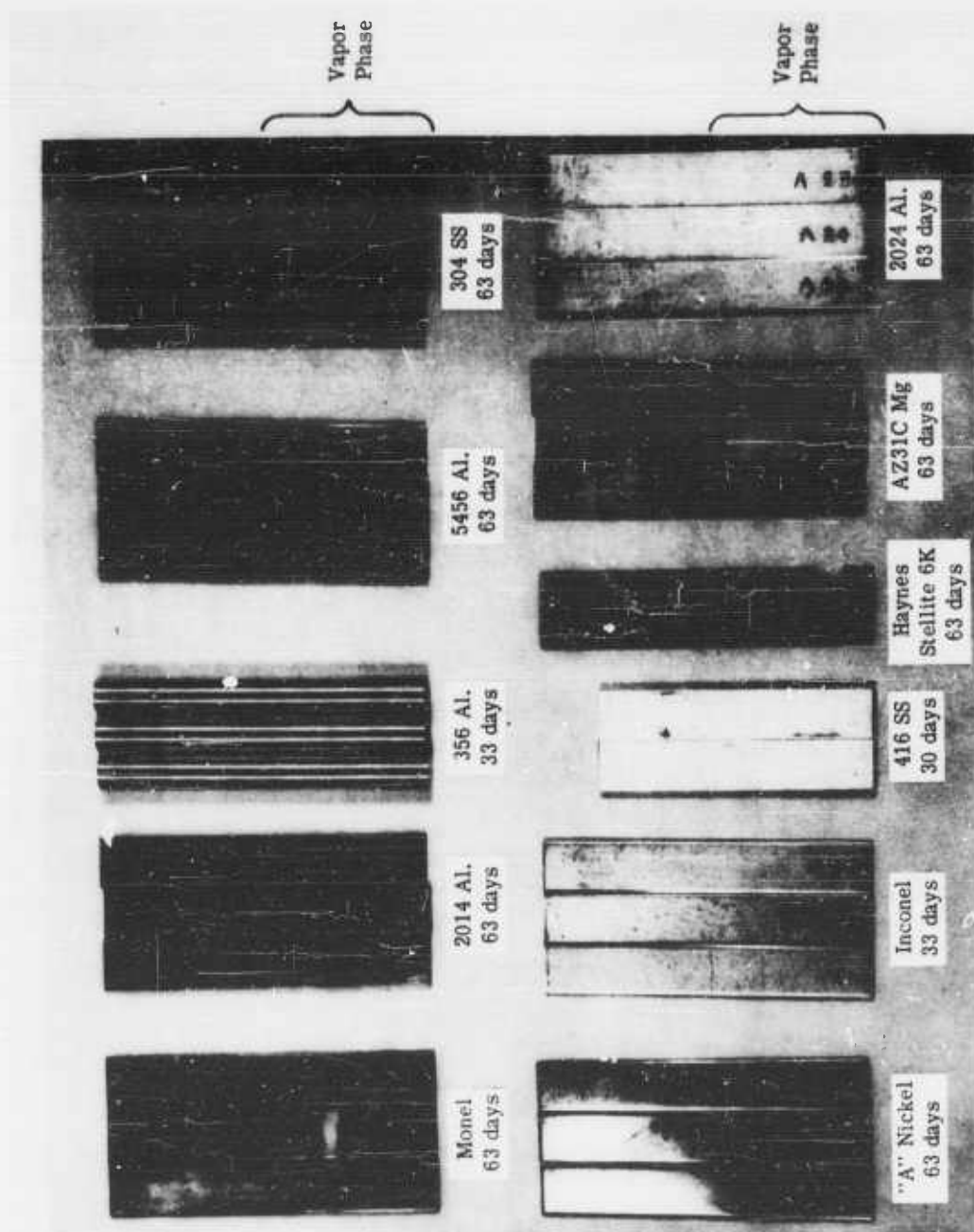
Figure 47. Metals Exposed to N_2O_4 at 60 ±5°F for Days Indicated
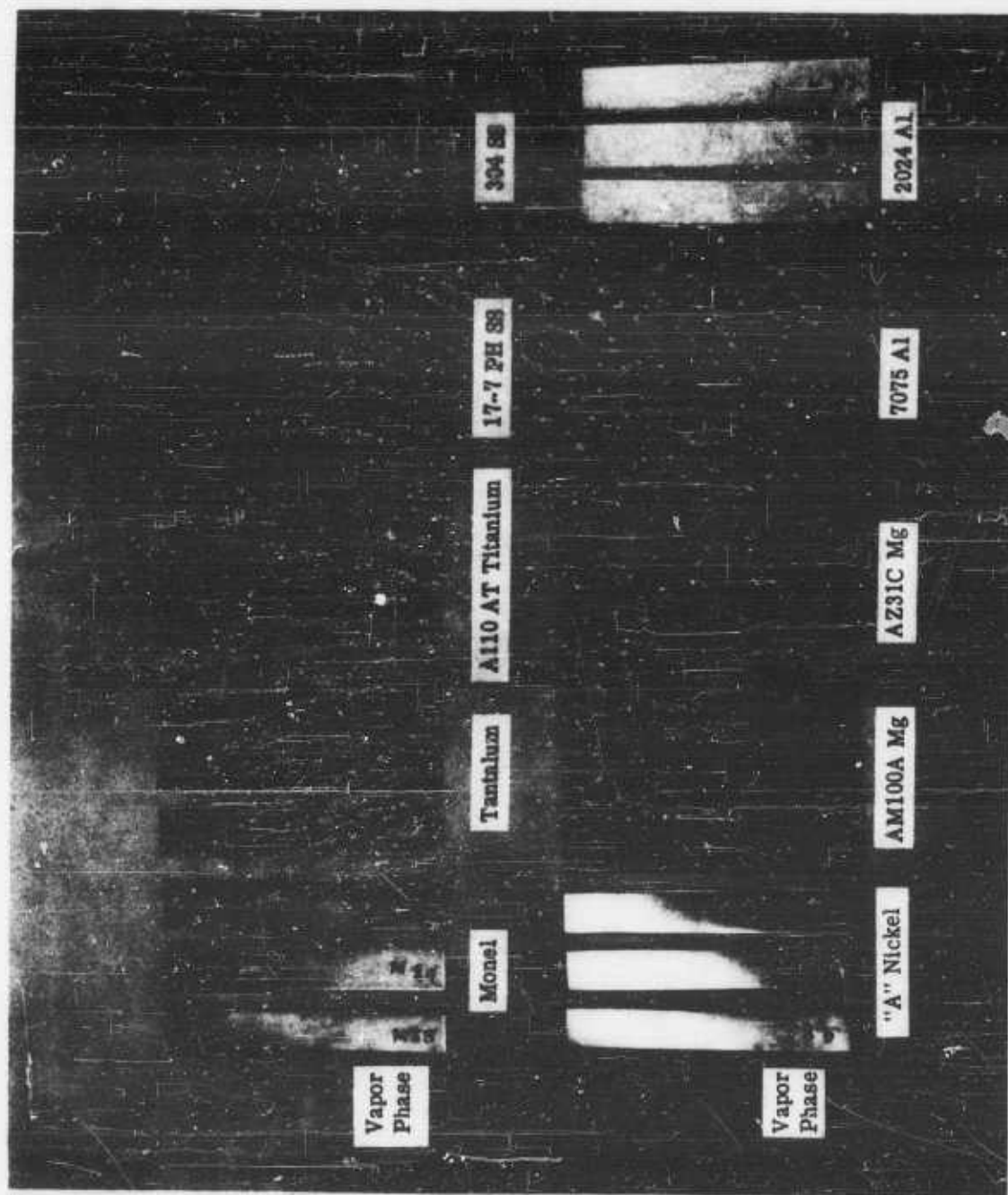
Figure 48. Metals Exposed to N_2O_4 60° ±5°F for One Month

110
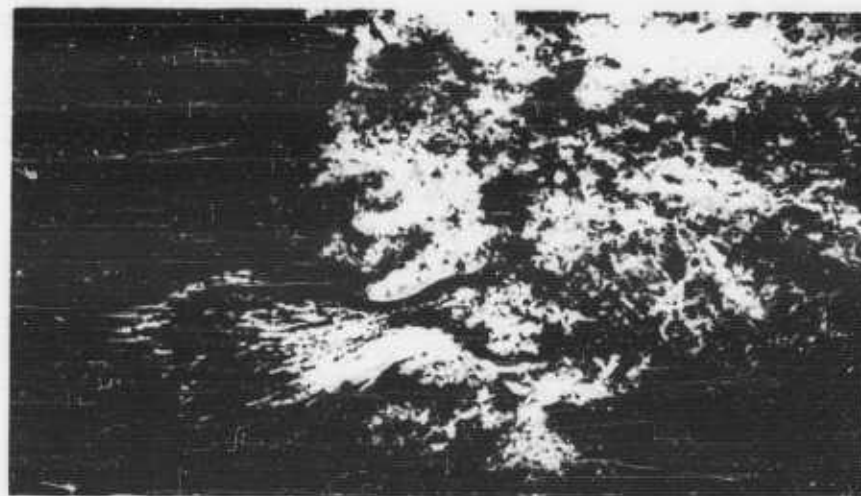
Figure 49. Impact Test of A 110 AT Titanium at 170 Ft-Lb After 30 Day
Exposure to N_2O_4

A 110 AT Titanium
30-Day Exposure
to N_2O_4

A 110 AT Titanium
Control
(Unexposed)

2024 Aluminum
30-Day Exposure
to N_2O_4

Figure 50. Impact Tests of Metal Coupons at 170 Ft-Lb
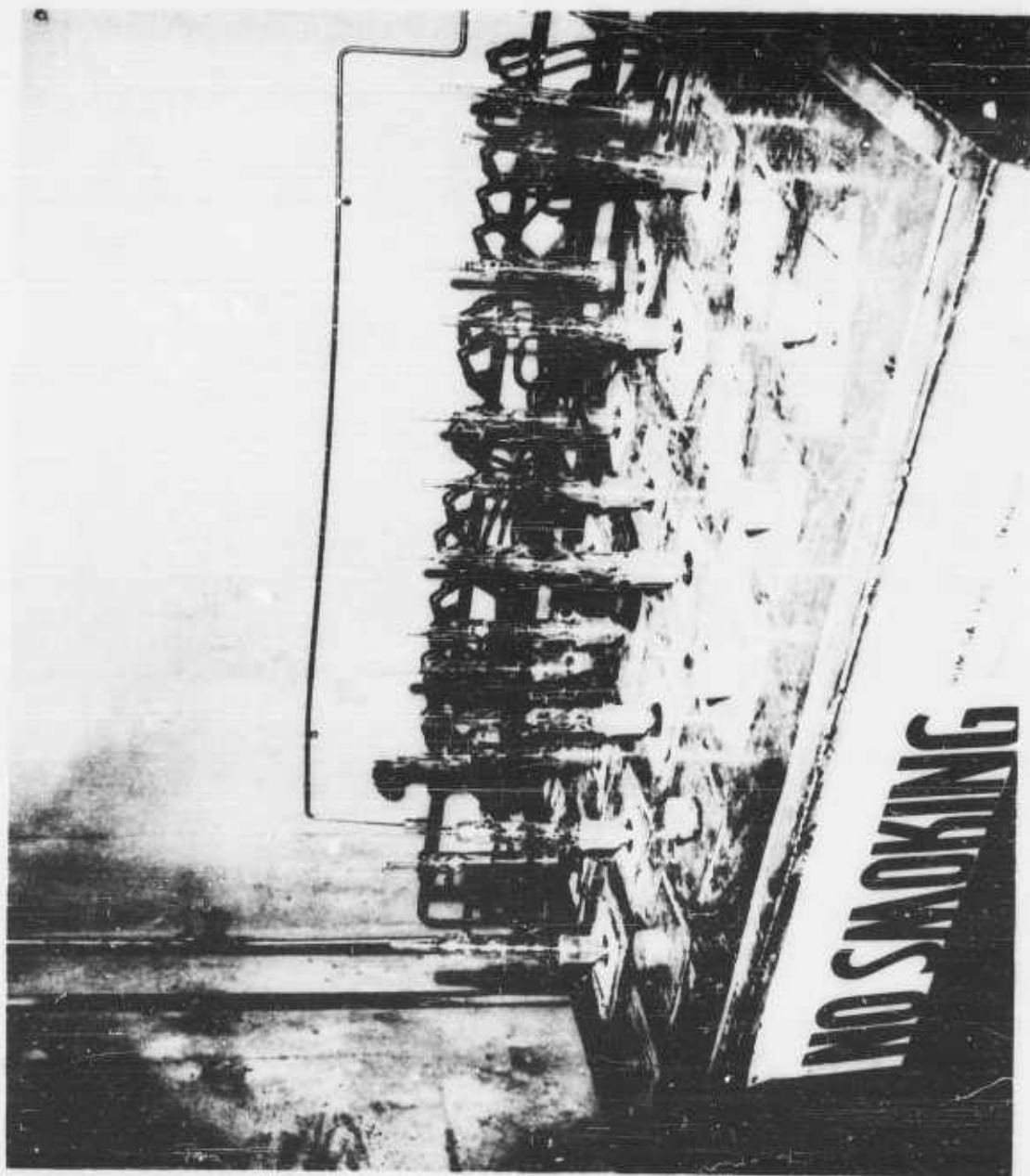
Figure 51. Materials Compatibility Test - Bath Set Up
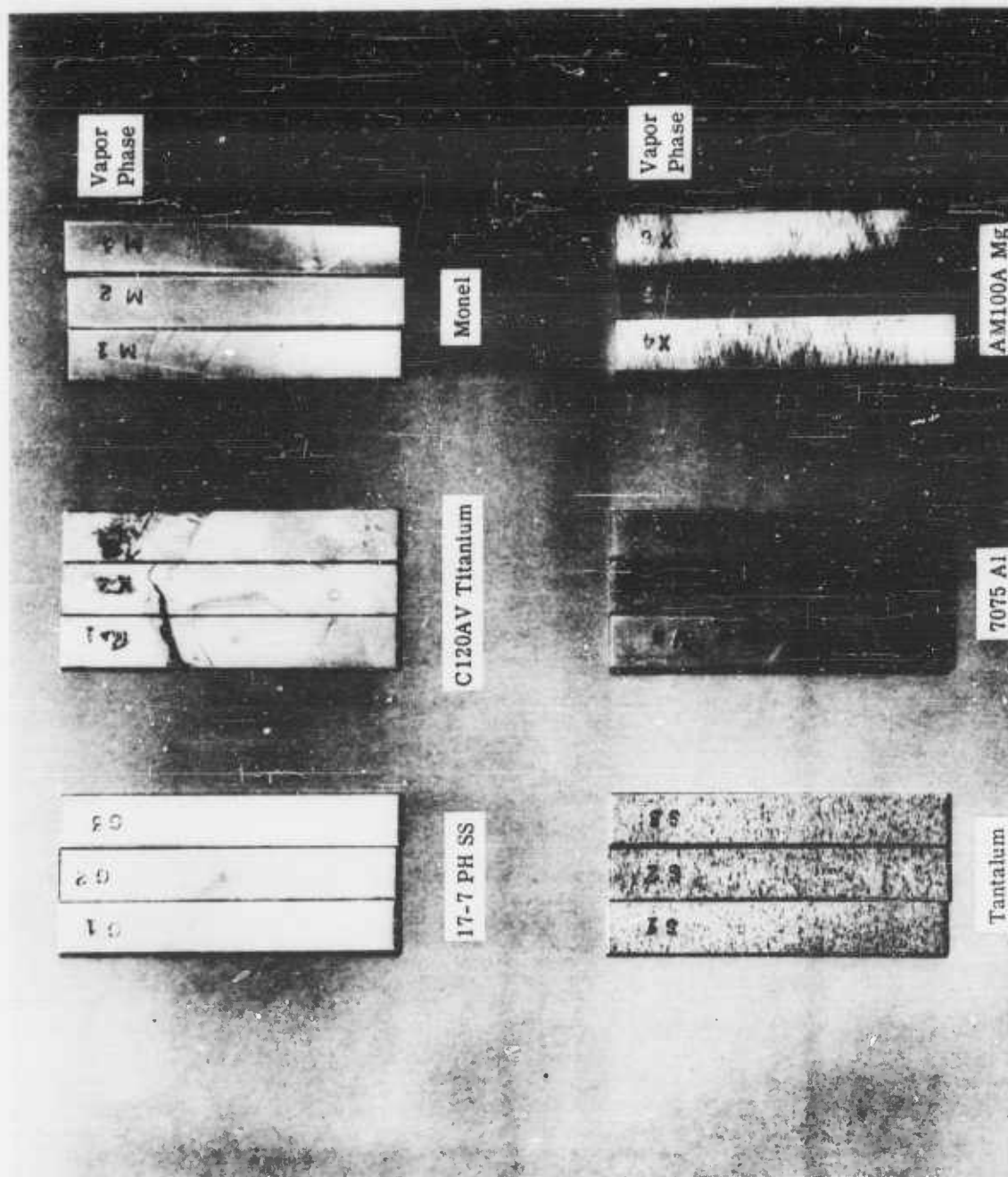
Figure 52. Metals Exposed to UDMH at 140°F for One Month
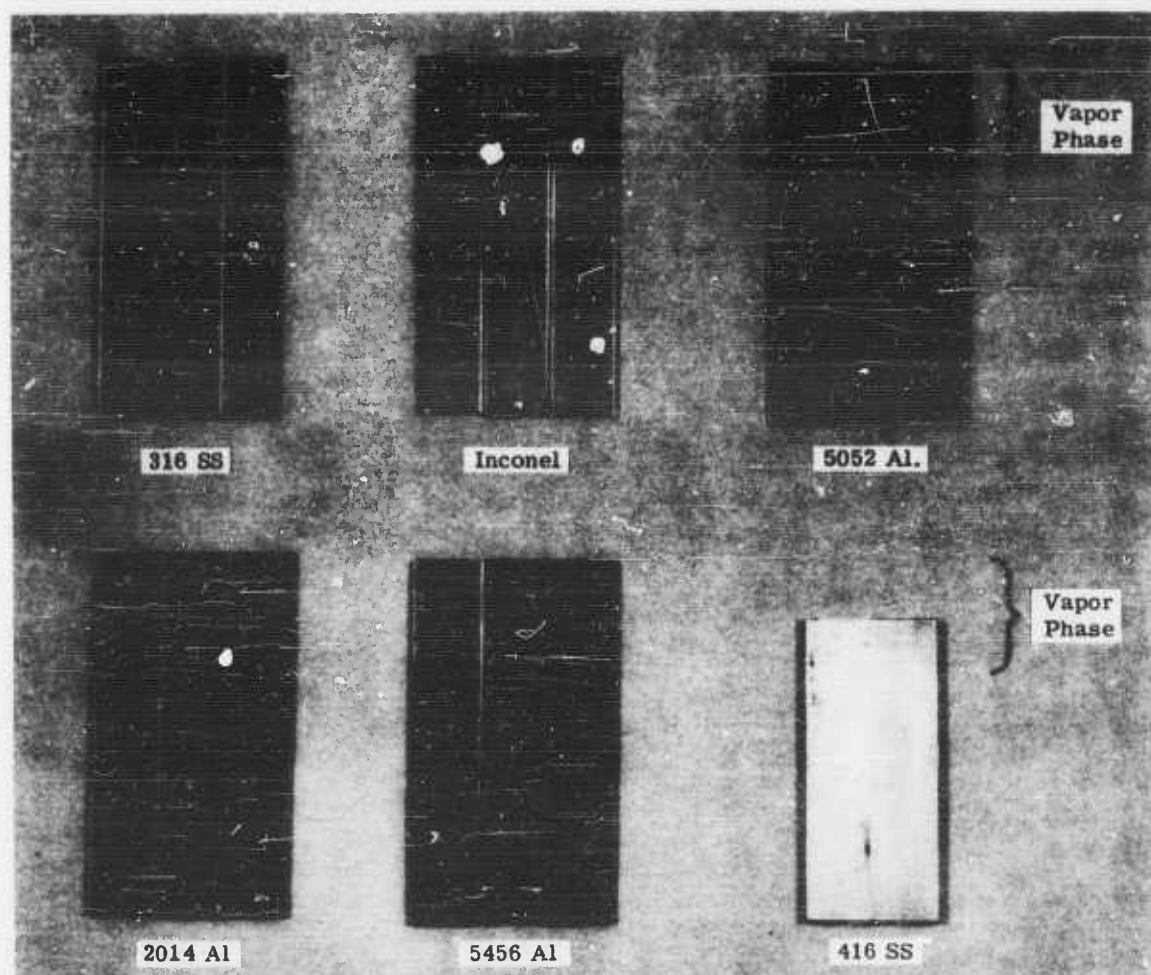
Figure 53. Metals Exposed to UDMH at 140°F for One Month
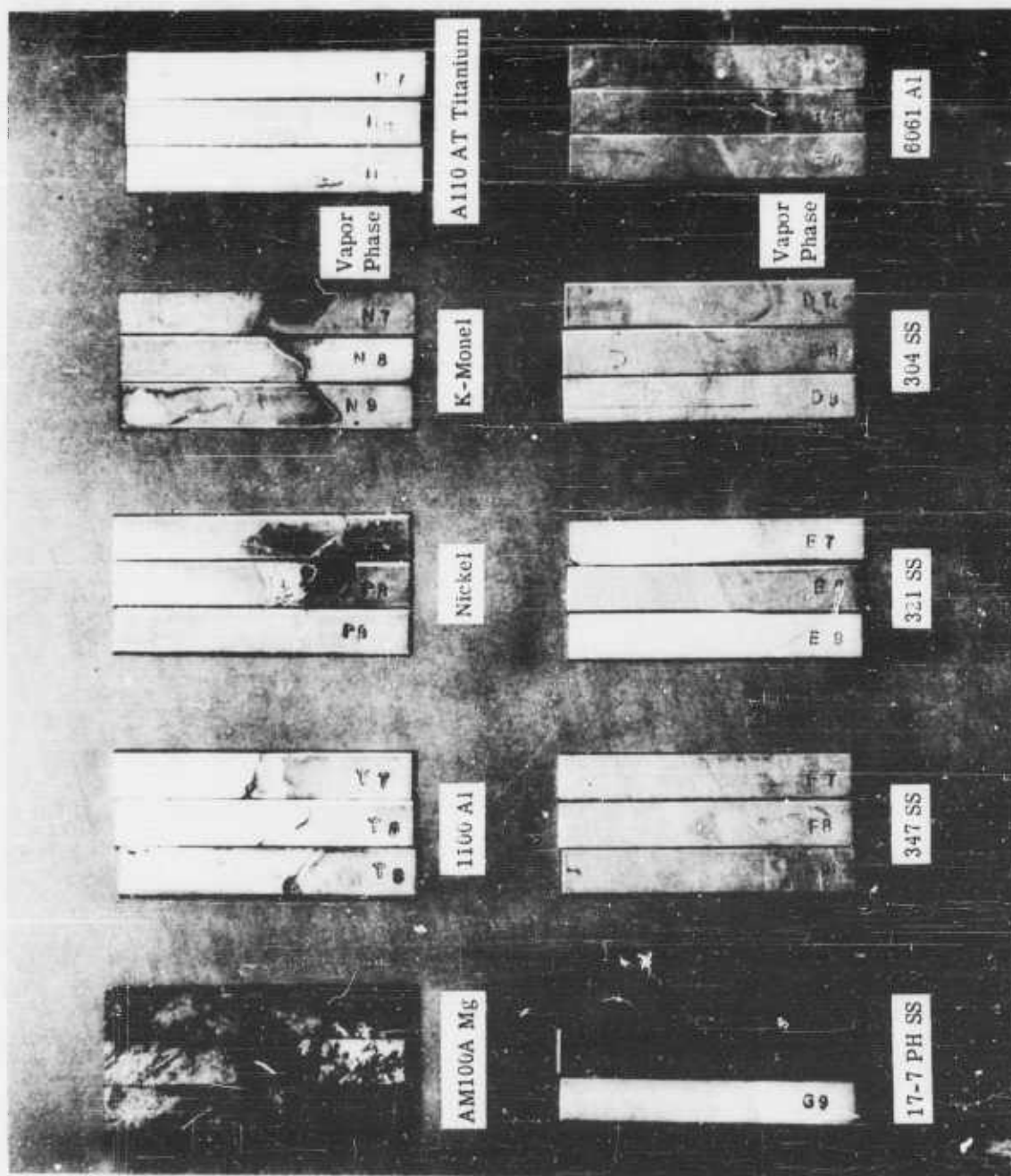
Figure 54. Metals Exposed to Hydrazine at 140°F for One Month
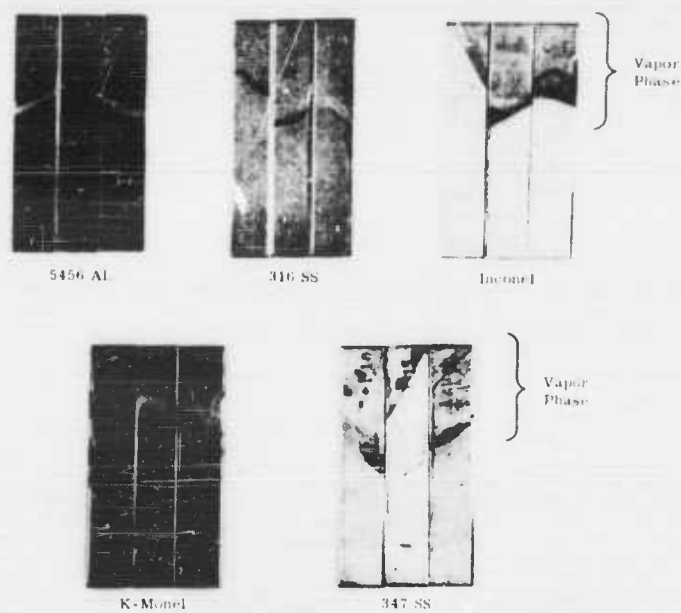
Figure 55. Metals Exposed to N_2H_4 at 200°F for One Month
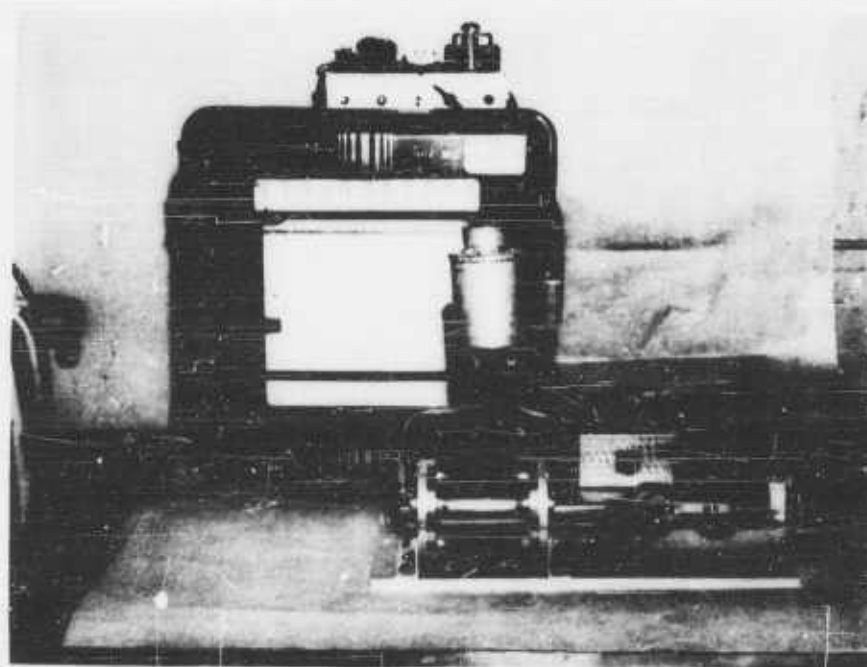
Figure 56. Lubricant Tester

TEST LIQUID – UDMH   TEST TEMP. – ambient
– Hydrazine

Graph Represents Smooth Curves Drawn Thru Data Obtained From Recorder Chart

LENGTH OF TEST – cycles (at 3 cycles per min.)
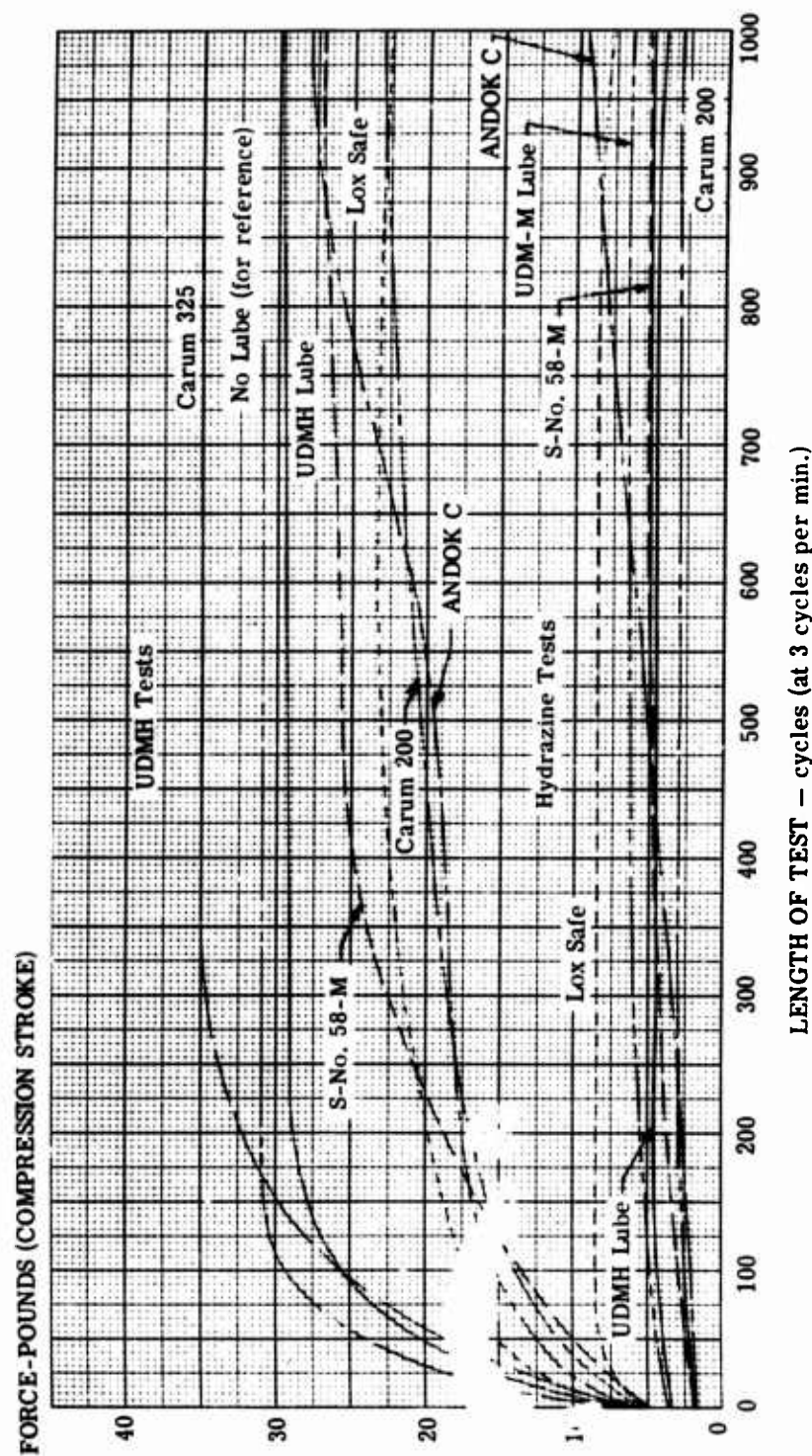
Figure 57. Test Results from Lubricant Tester
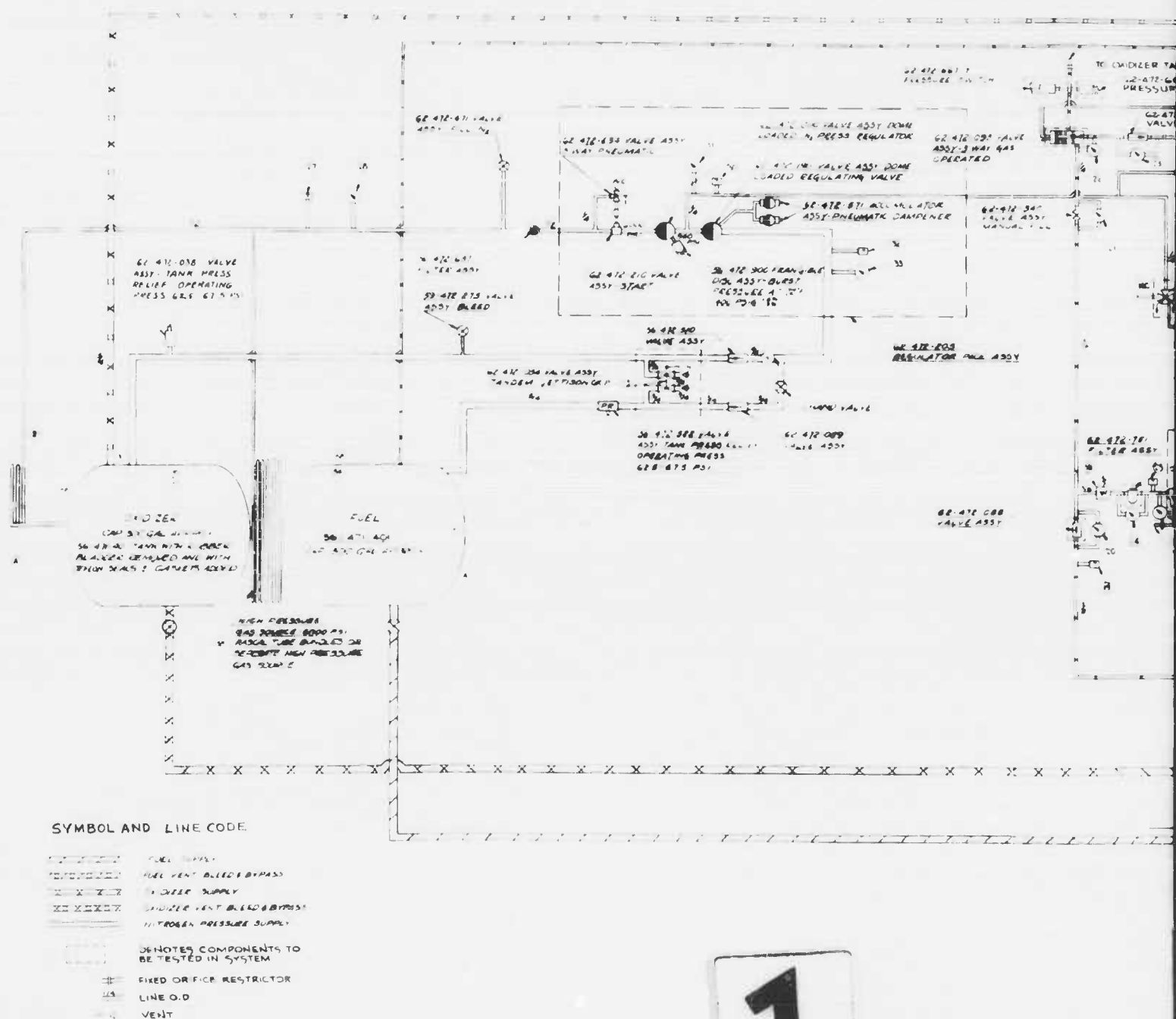
Figure 58. Schematic for System Flow Tests (Sheet 1 of 2)

NO.	LOCATION	RANGE	NAME
39	Oxidizer Flow	1" Flowrate	Potter Flow Raters
38	Oxidizer Flow	3/8" Flowrate	Potter Flow Raters
37	Oxidizer Flow	3/8" Flowrate	Potter Flow Raters
36	Fuel Flow	3/4" Flowrate	Potter Flow Raters
35	Fuel Flow	1/2" Flowrate	Potter Flow Raters
34	Fuel Flow	1/2" Flowrate	Potter Flow Raters
33	Nitrogen 2nd Stage Pressure	0-100 Psig	Crosby, Gauge, Pressure
32	Nitrogen 2nd Stage Pressure	0-100 Psig	Taber, Pressure Transducer
31	Nitrogen 1st Stage Pressure	0-1000 Psig	Crosby, Gauge, Pressure
30	Nitrogen 1st Stage Pressure	0-1000 Psig	Taber, Pressure Transducer
28	Nitrogen Source Pressure	0-6000 Psig	Crosby, Gauge, Pressure
27	Nitrogen Source Pressure	0-6000 Psig	Taber, Pressure Transducer

NITROGEN

NO.	LOCATION	RANGE	NAME
26	Δ P Oxidizer (62-472-367)	0-50 Psi	Δ P Gauge, Statham or Visual
25	Oxidizer Inlet Pressure (62-472-367)	0-1000 Psig	Taber, Pressure Transducer
24	Δ P Oxidizer (62-472-751)	0-50 Psi	Δ P Gauge, Statham or Visual
23	Δ P Oxidizer (62-472-087)	0-50 Psi	Δ P Gauge, Statham or Visual
22	Δ P Oxidizer (62-472-093)	0-50 Psi	Δ P Gauge, Statham or Visual
21	Δ P Oxidizer (62-472-340)	0-50 Psi	Δ P Gauge, Statham or Visual
20	Δ P Oxidizer (62-472-088)	0-50 Psi	Δ P Gauge, Statham or Visual
19	Oxidizer Inlet Pressure (62-472-088)	0-1000 Psig	Taber, Pressure Transducer
18	Δ P Oxidizer (62-472-213)	0-50 Psi	Δ P Gauge, Statham or Visual
17	Oxidizer Inlet Pressure (62-472-213)	0-1000 Psig	Taber, Pressure Transducer
16	Δ P Oxidizer (62-472-163)	0-50 Psi	Δ P Gauge, Statham or Visual
15	Oxidizer Inlet Pressure (62-472-163)	0-1000 Psig	Taber, Pressure Transducer
14	Oxidizer Tank Pressure	0-1000 Psig	Crosby, Gauge, Pressure
13	Oxidizer Tank Pressure	0-1000 Psig	Taber, Pressure Transducer

OXIDIZER

NO.	LOCATION	RANGE	NAME
29	Δ P Fuel (62-472-413)	0-50 Psi	Δ P Gauge, Statham or Visual
12	Δ P Fuel (62-472-367)	0-50 Psi	Δ P Gauge, Statham or Visual
11	Δ P Fuel (62-472-087)	0-50 Psi	Δ P Gauge, Statham or Visual
10	Δ P Fuel (62-472-093)	0-50 Psi	Δ P Gauge, Statham or Visual
9	Δ P Fuel (62-472-340)	0-50 Psi	Δ P Gauge, Statham or Visual
8	Δ P Fuel (62-472-089)	0-50 Psi	Δ P Gauge, Statham or Visual
7	Fuel Inlet Pressure (62-472-089)	0-1000 Psig	Taber, Pressure Transducer
6	Δ P Fuel (62-472-213)	0-50 Psi	Δ P Gauge, Statham or Visual
5	Fuel Inlet Pressure (62-472-213)	0-1000 Psig	Taber, Pressure Transducer
4	Δ P Fuel (62-472-163)	0-50 Psi	Δ P Gauge, Statham or Visual
3	Fuel Inlet Pressure (62-472-163)	0-1000 Psig	Taber, Pressure Transducer
2	Fuel Tank Pressure	0-1000 Psig	Crosby, Gauge, Pressure
1	Fuel Tank Pressure	0-1000 Psig	Taber, Pressure Transducer

FUEL

NO.	LOCATION	RANGE	NAME

QTY column (right, partially cut off):

QTY	P/N
1	62-4
1	59-4
1	62-4
3	62-4
1	62-4
1	62-4
1	62-4
1	62-4
1	62-4
1	62-4
1	62-4
1	P/N
1	59-4
1	62-4
1	62-4
1	62-4
1	62-4
1	62-4
1	62-4
1	62-4
1	62-4
2	62-4

INSTRUMENTATION REQUIRED FOR CALIBRATION

1

AFFTC TR-60-61

STORABLE PROPELLANT FLOW SYSTEM COMPONENTS

QTY		FUEL SYSTEM
1	62-472-667-5	Pressure Switch
1	59-472-275-1	Valve Assy
1	62-472-163-5	TCPV
3	62-472-413-1	Marotta Solenoid Valves
1	62-472-213-5	By-Pass Valve
1	62-472-089-1	Check Valve
1	62-472-340-1	Manual Fill Valve
1	62-472-093-5	Gas Operated 3-Way Valve
1	62-472-087-1	Check Valve
1	62-472-667-1	Pressure Switch
1	62-472-367-1	Gas Generator
1	P/N 83 or 62-472-034-1	Valve Assy

OXIDIZER SYSTEM

1	59-472-275-1	Valve
1	62-472-088-1	Check Valve
1	62-472-340-1	Manual Fill Valve
1	62-472-093-5	Gas Operated 3-Way Valve
1	62-472-087-1	Check Valve
1	62-472-667-7	Pressure Switch
1	62-472-667-3	Pressure Switch
1	62-472-751-1	Filter Assy

PRESSURIZATION SYSTEM

1	62-472-205-3	N₂ Regulator Pack
2	62-472-412-1	Whittaker 5-Way Solenoid Valves

1	62-472-038 Tank Pressure Relief Valve
1	59-472-275 Bleed Valve
1	56-472-522 Pressure Relief Valve
1	3/4" Globe Hand Valve

PRESSURIZATION SYSTEM

2	1 Inch Circle Seal Check Valve
1	Oxidizer Tank (56-471-401 Modified See F/D)
2	1" Gate Hand Valves
1	3/4" Circle Seal Check Valve
1	15 H Grove Hand Loader Regulator
1	300 Series Grove Dome Loaded Regulator
1	1-1/4" Turansky Valve
1	Lonergan S.S. Pop Safety Valve
2	General Control 3-Way Solenoid Valves
1	1-1/4" N. C. Turansky Valve
1	100 Gal. S.S. Tank WP-1000 Psig

OXIDIZER SYSTEM

2	3/4" Circle Seal Check Valve
1	Fuel Tank (56-471-401)
2	3/4" Gate Hand Valves
1	1/2" Circle Seal Check Valve
1	15H Grove Hand Loader Regulator
1	200 Series Grove Dome Loaded Regulator
1	1-1/4" N.O. Turansky Valve
1	1" Lonergan S.S. Pop Safety Valve
2	General Control 3-Way Solenoid Valves
1	1-1/4" N.C. Turansky Valve
1	100 Gal. S.S. Tank WP-1000 Psig

FUEL SYSTEM

QTY	DESCRIPTION

BILL OF MATERIAL

Figure 58. Schematic for System Flow Tests (Sheet 2 of 2)

119
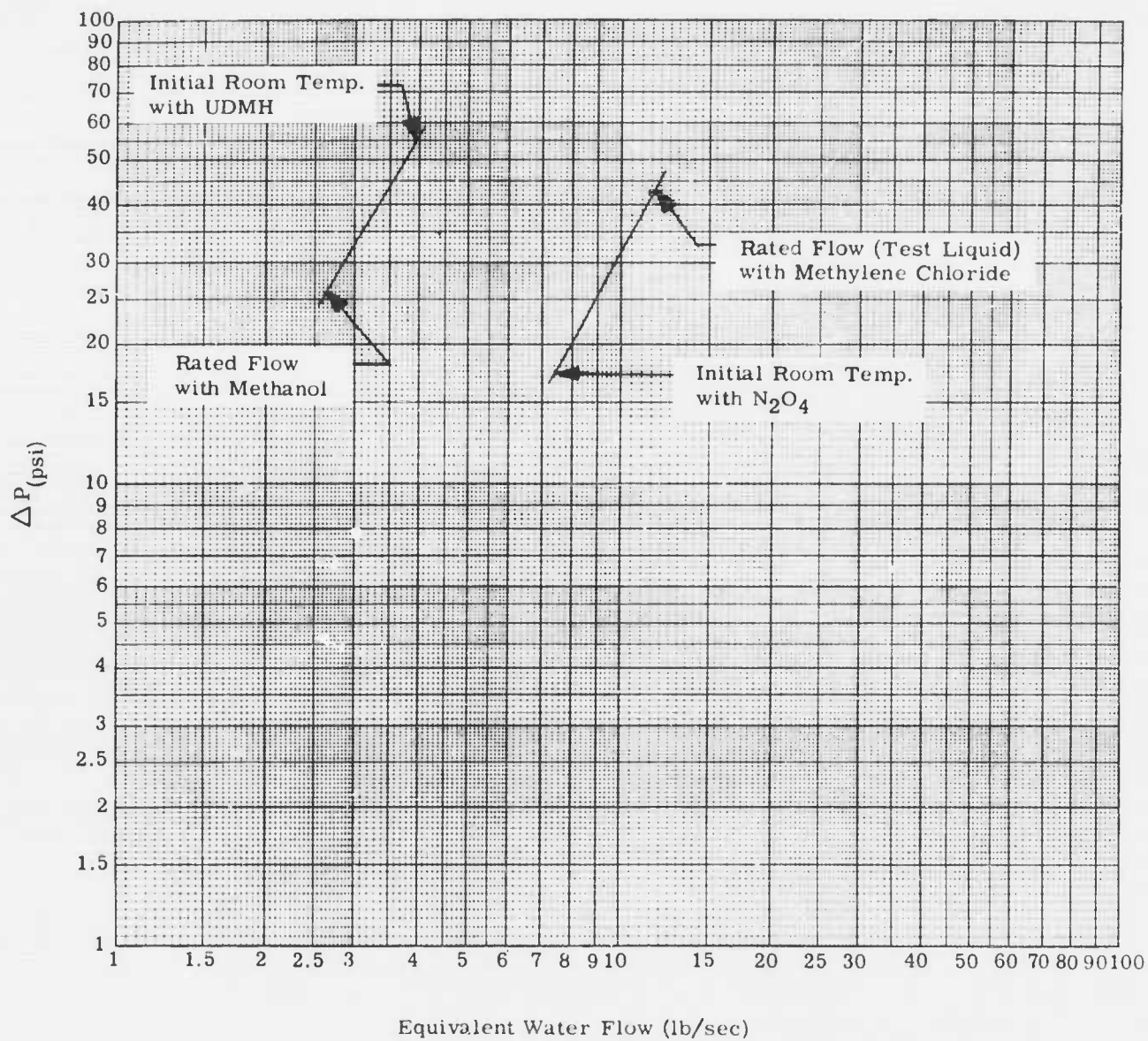
Figure 59. 62-472-163-5 Thrust Chamber Propellant Valve
(Fuel and Oxidizer) Flow vs $\triangle$ P
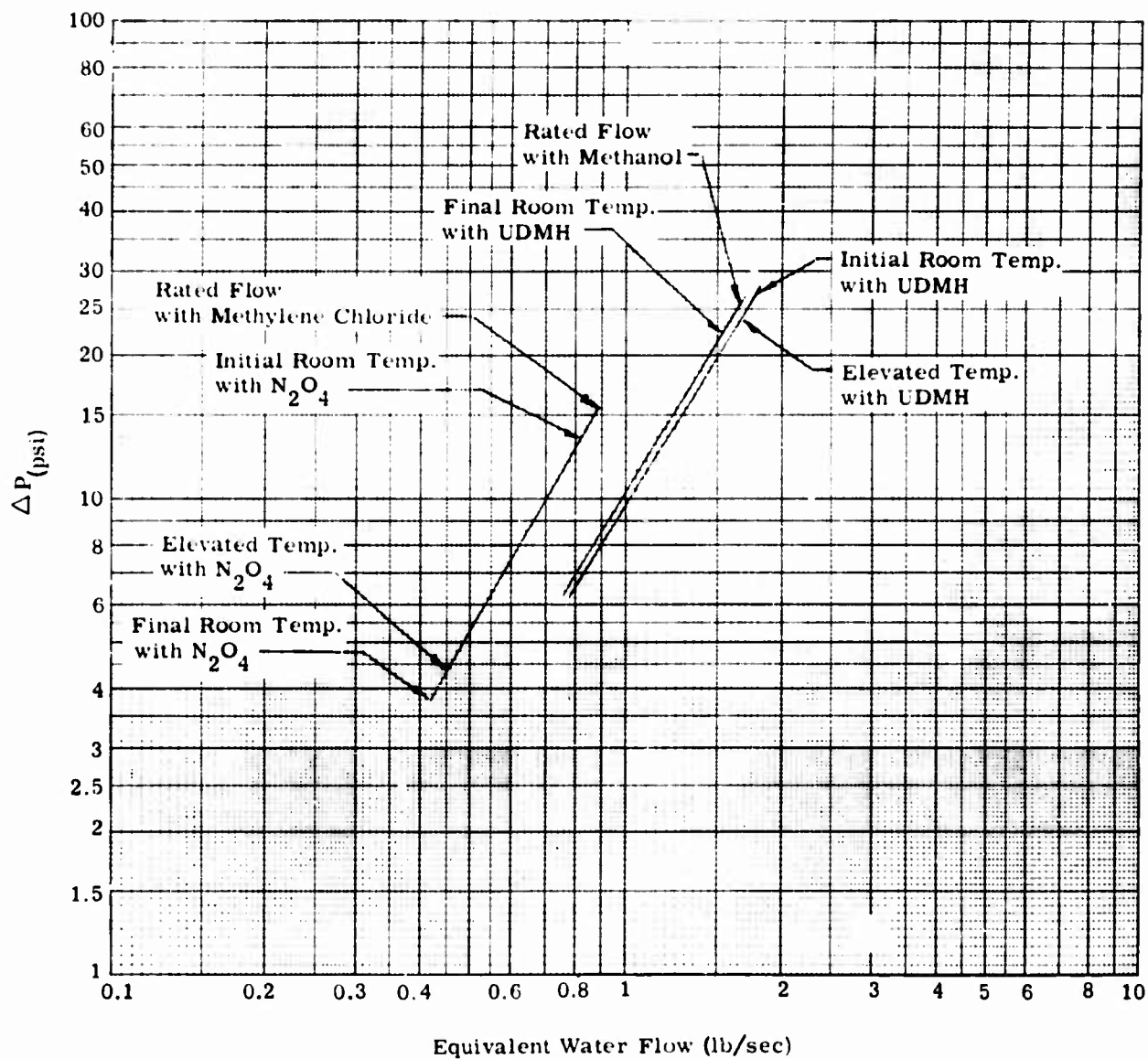
Figure 60. 62-472-367-1 Gas Generator Propellant Valve - Flow vs $\triangle$ P
(Fuel and Oxidizer)
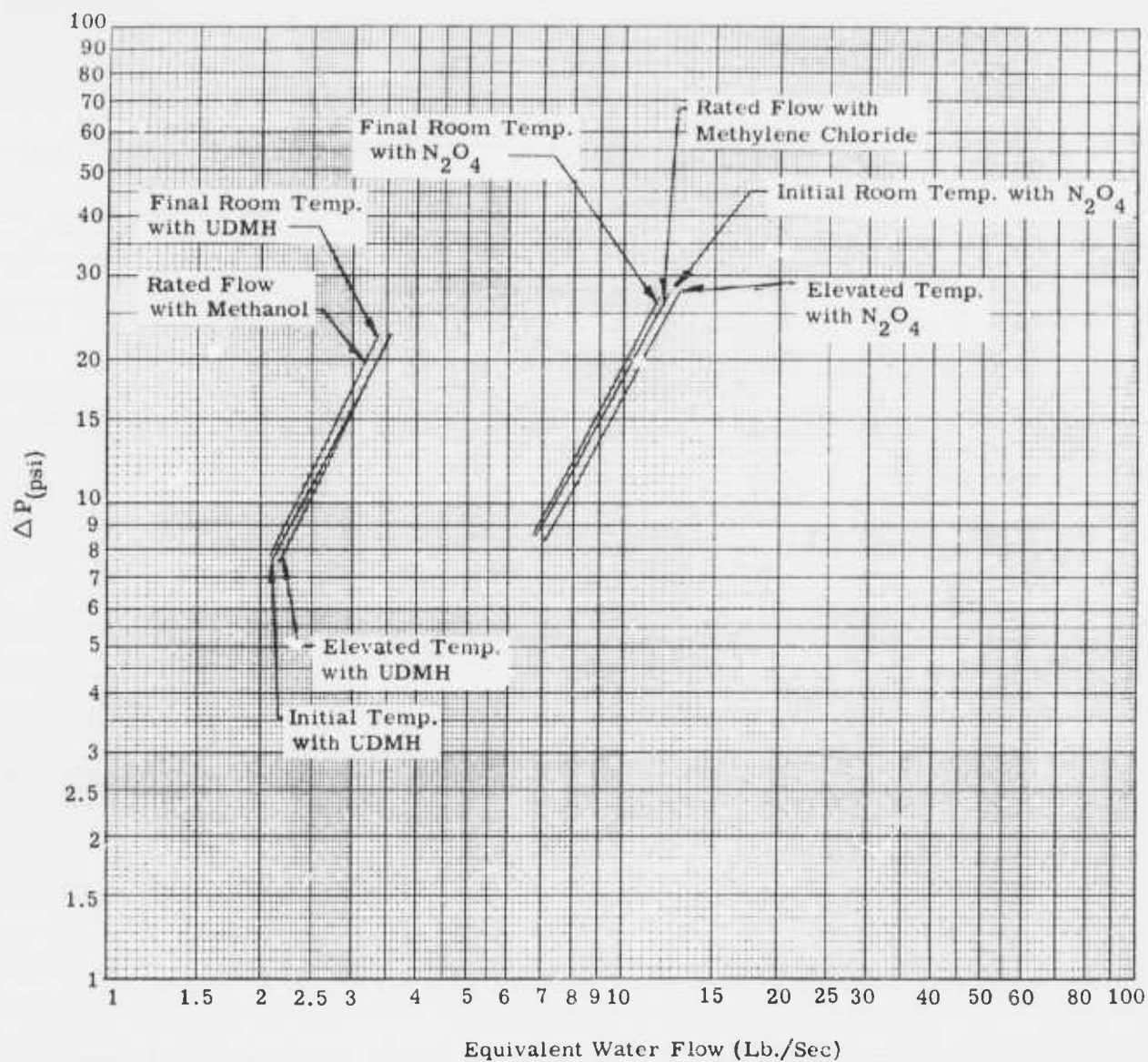
Figure 61. 62-472-213-5 Turbine Bypass Valve - Flow vs $\triangle$P (Fuel and Oxidizer)
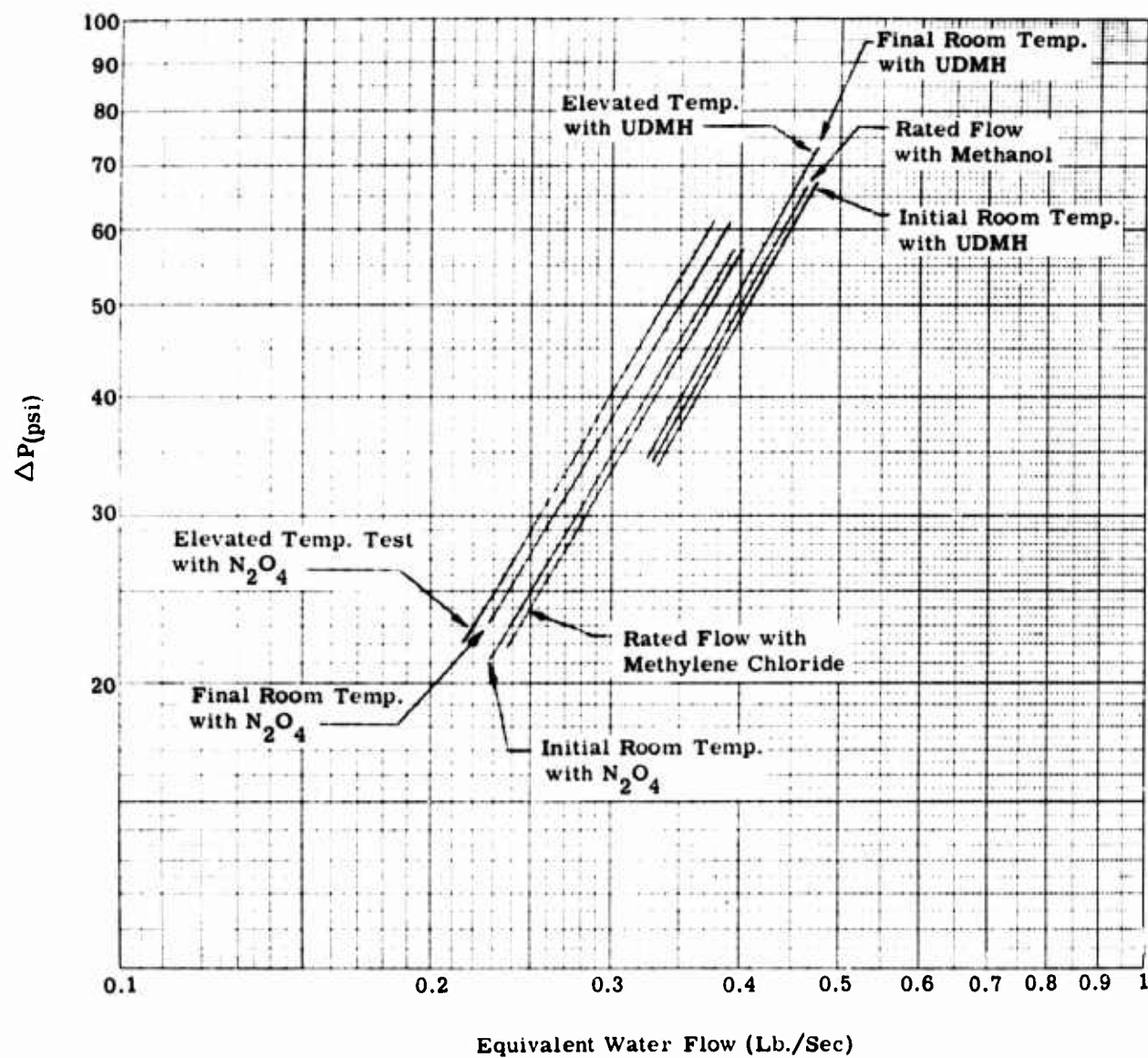
Figure 62. 62-472-340-1 Manual Fill Valve - Flow vs $\triangle P$ (Fuel and Oxidizer)
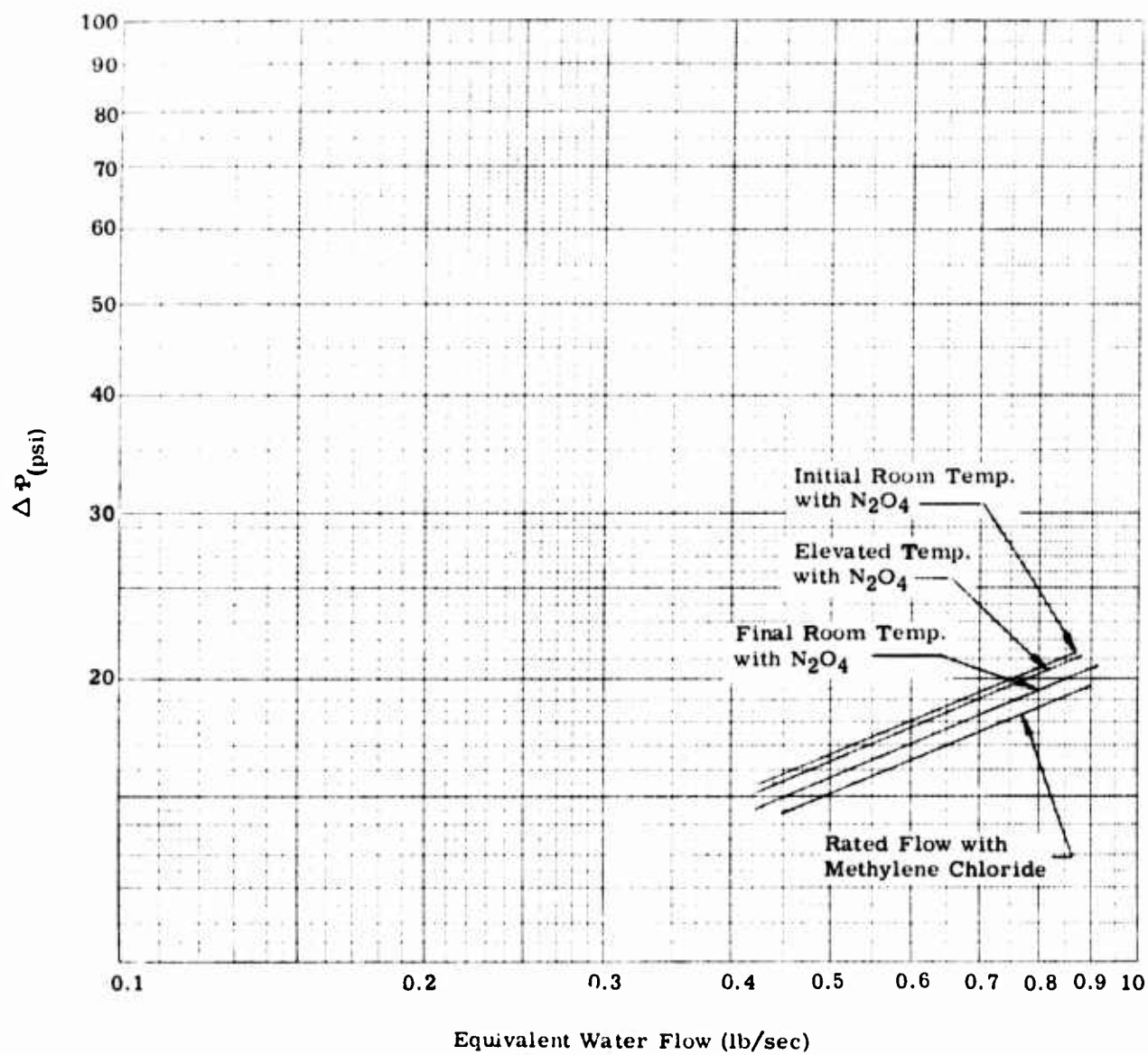
Figure 63. 62-472-088-1 Oxidizer Check Valve - Flow vs $\triangle$ P
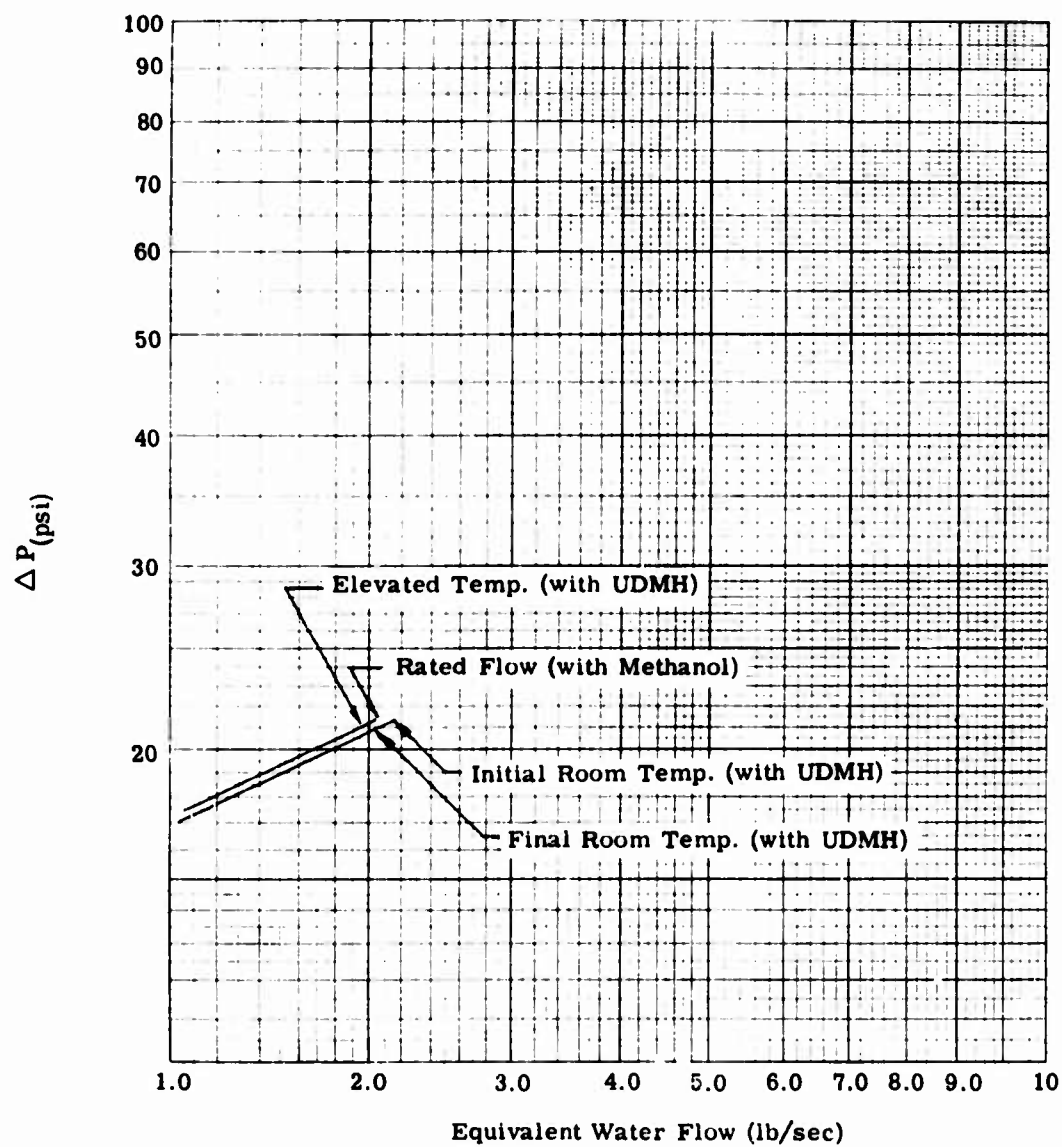
Figure 64. 62-472-089-1 Fuel Check Valve - Flow vs $\triangle$ P
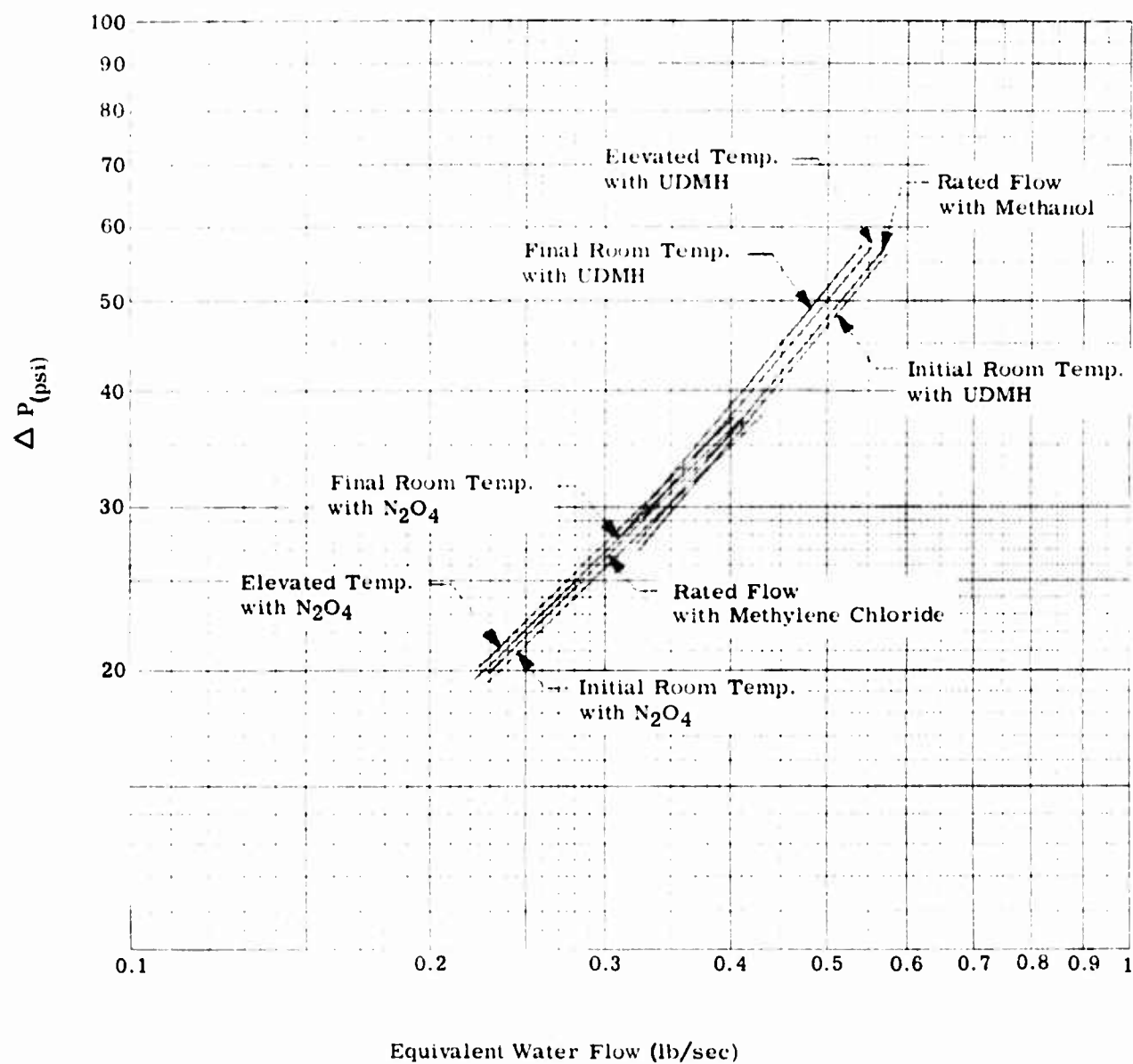
Figure 65. 62-472-087-1 Check Valve - Flow vs Δ P (Fuel and Oxidizer)
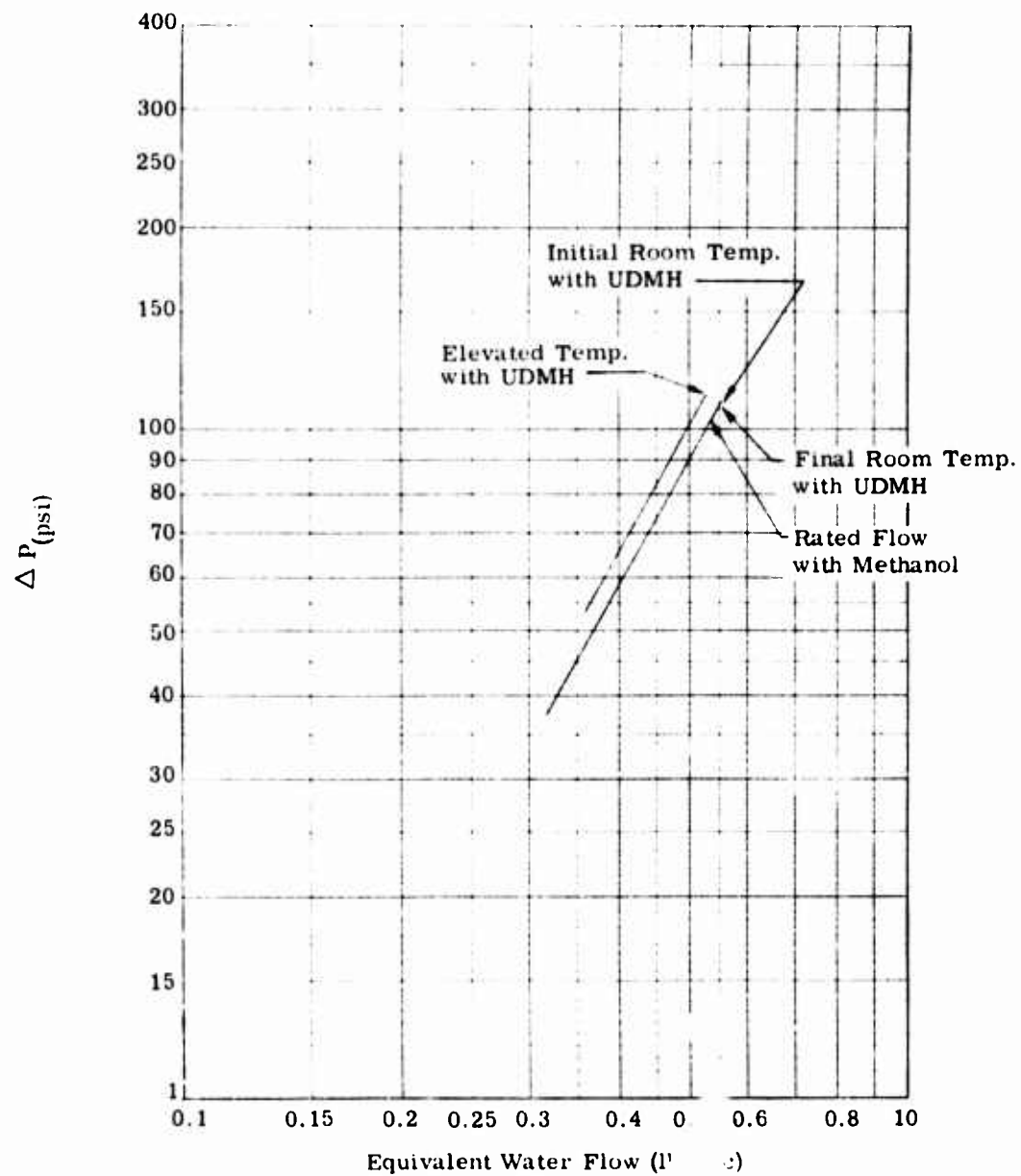
Figure 66. 62-472-413-1 Marotta Solenoid Valve - Flows ΔP
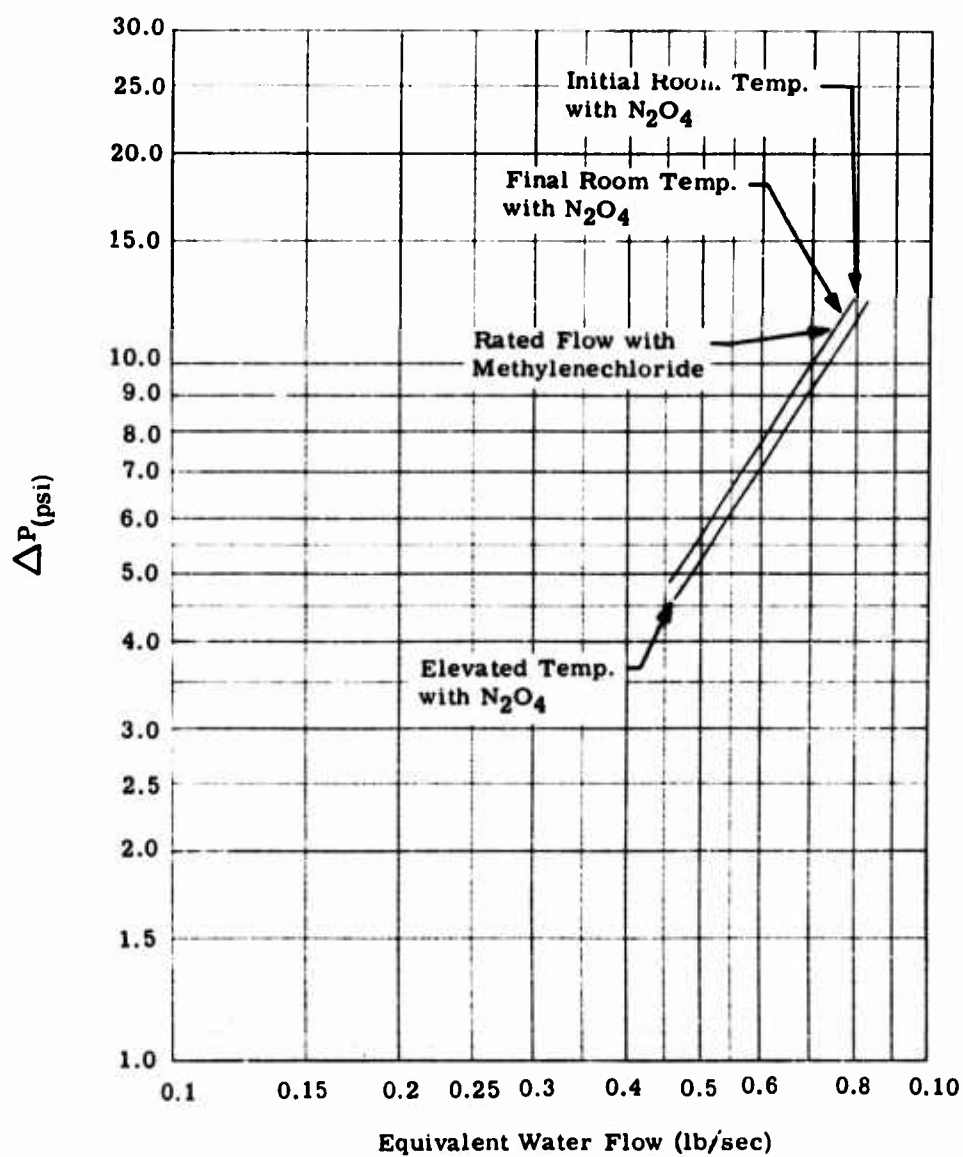
Figure 67. 62-472-751-1 Oxidizer Filter Assembly - Flow vs $\triangle$ P
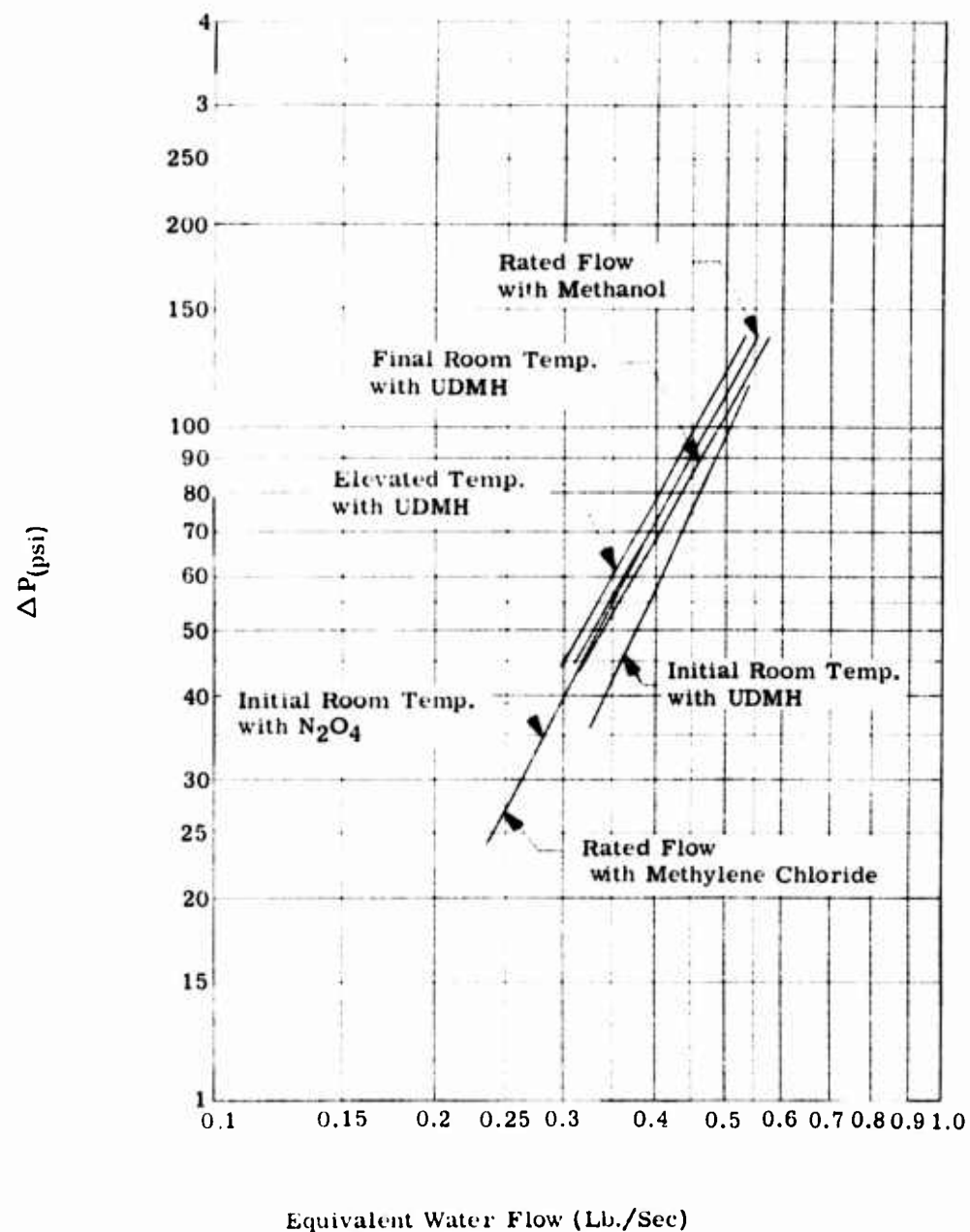
Figure 68. 62-472-093-5 Gas Operated Three-Way - Flow vs Δ P
(Fuel and Oxidizer)
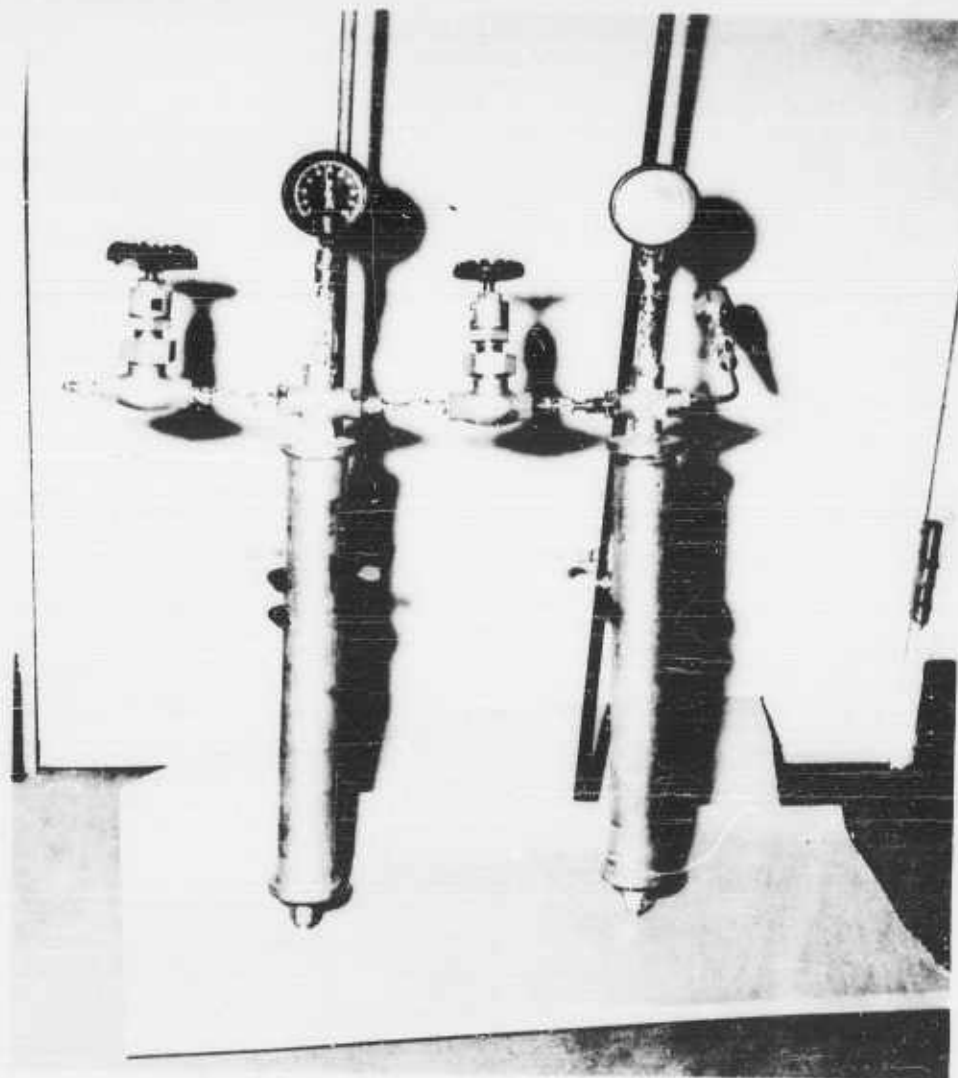
Figure 69. Gas Solubility Apparatus
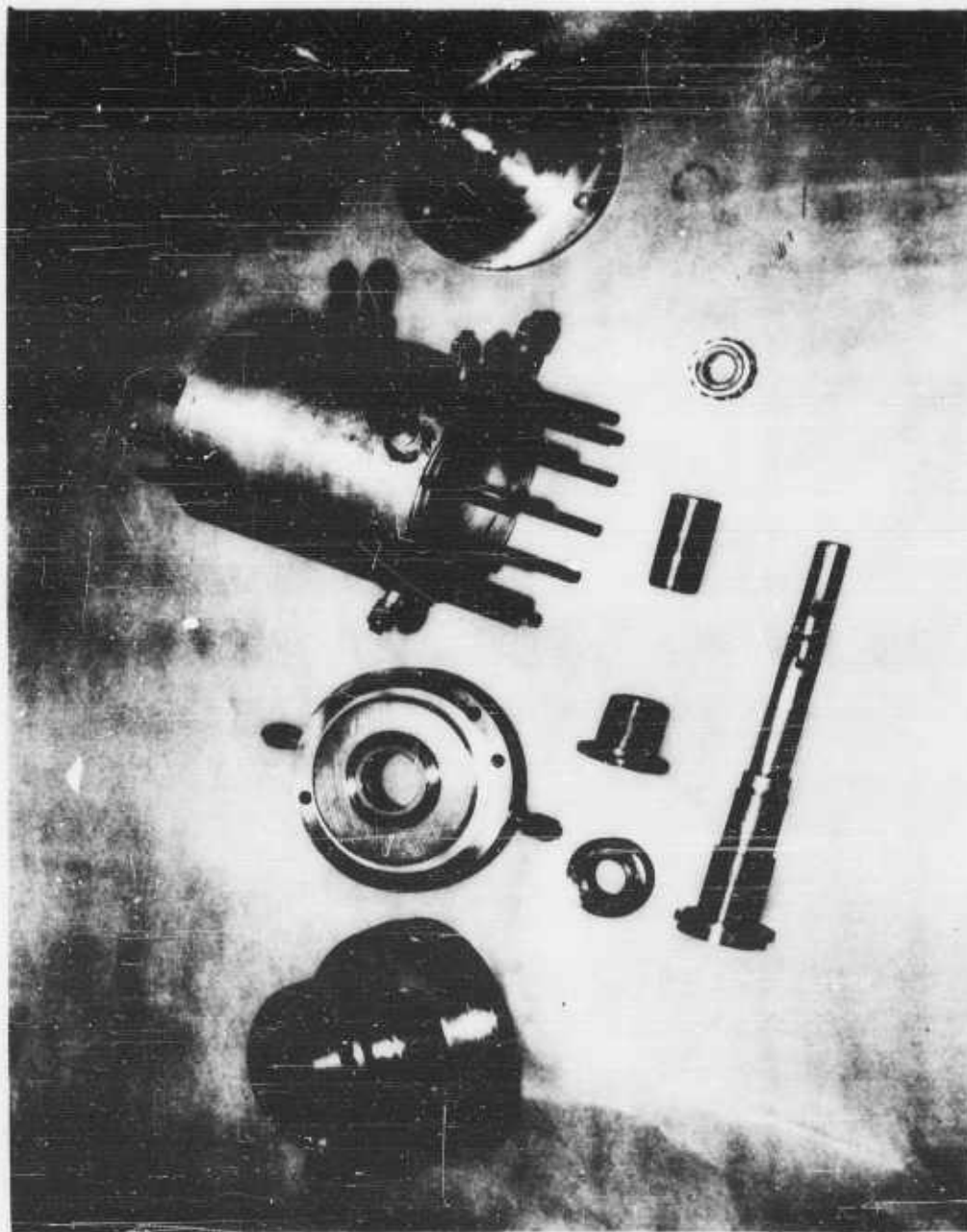
Figure 70. Seal Test Rig
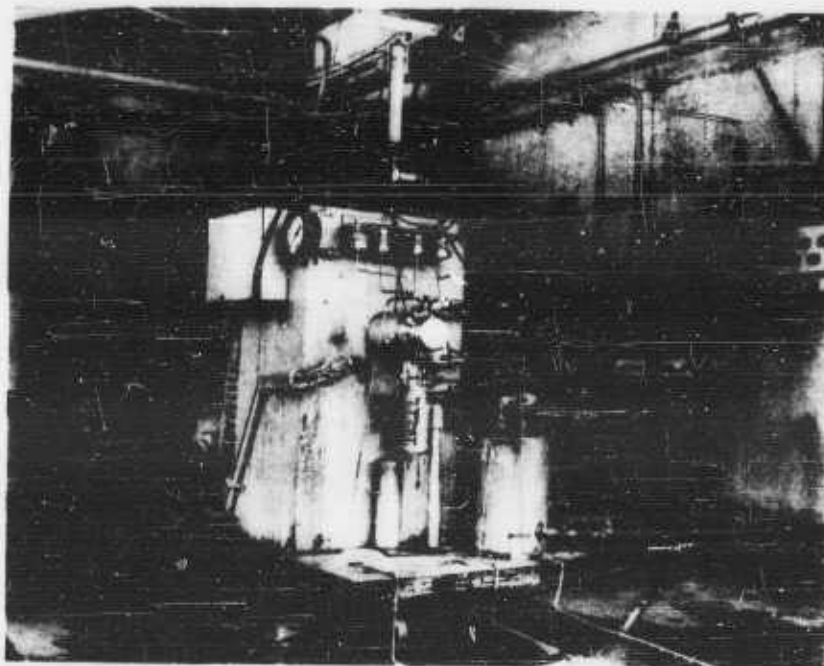
Figure 71. Seal Test Fixture on Vari-Drive
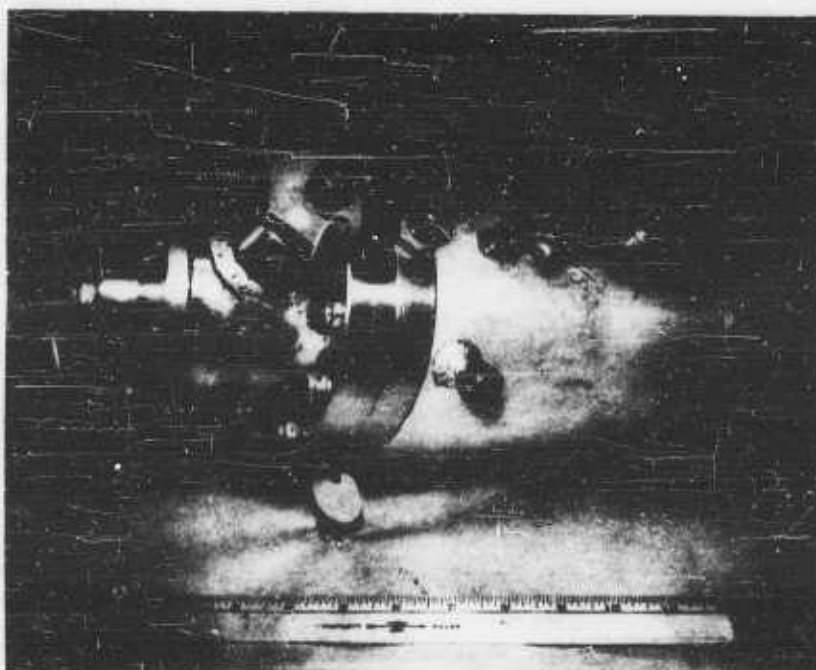
Figure 72. Assembled Seal and Bearing Test Rig
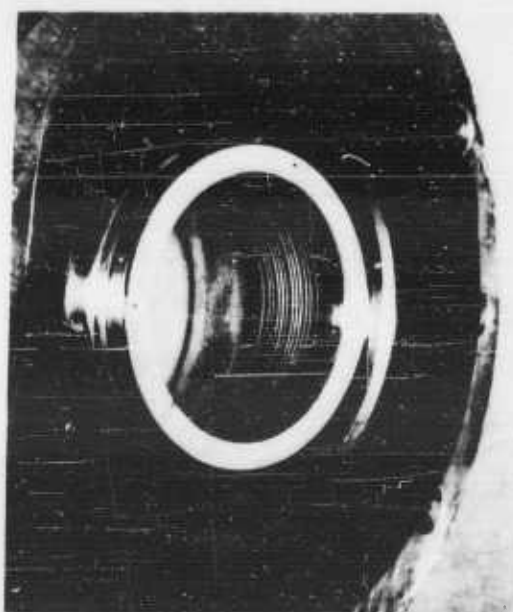
Figure 73. Glass Impregnated Teflon Face,
Type 347 Stainless Steel Bellows Seal
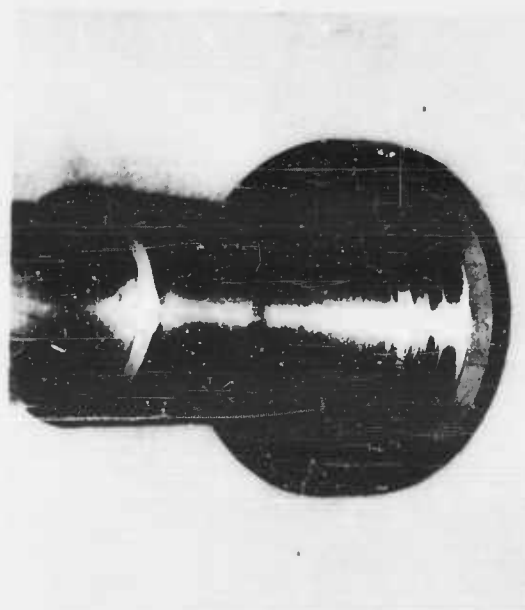
Figure 74. Type 316 Stainless Steel
Mating Ring
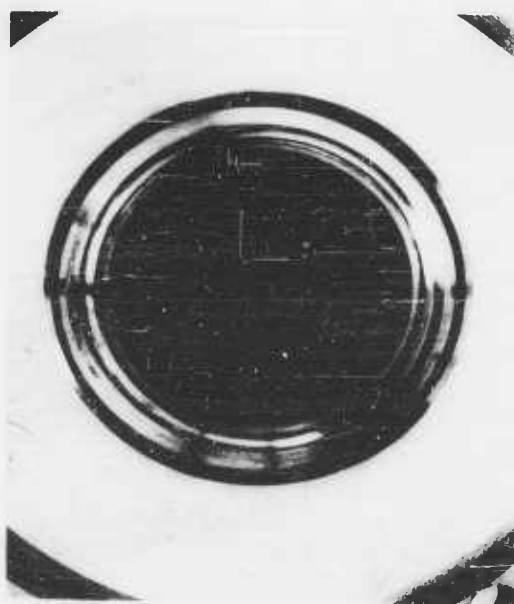
Figure 75. Graphitar G-39 Carbon Face,
AMS 350 Stainless Steel Bellows Seal
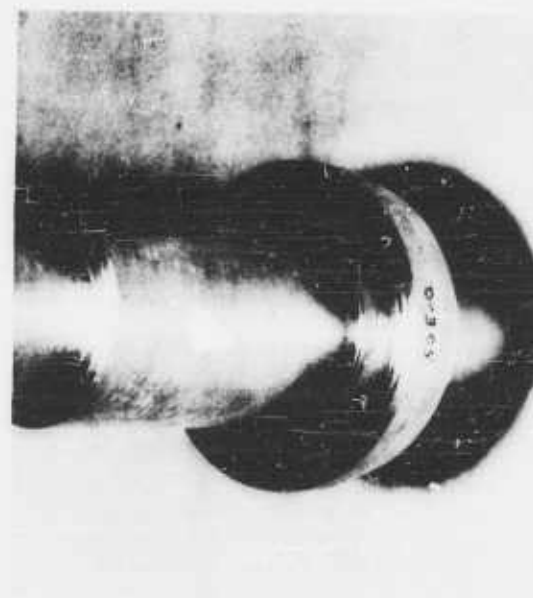
Figure 76. Type 316 Stainless Steel
Mating Ring
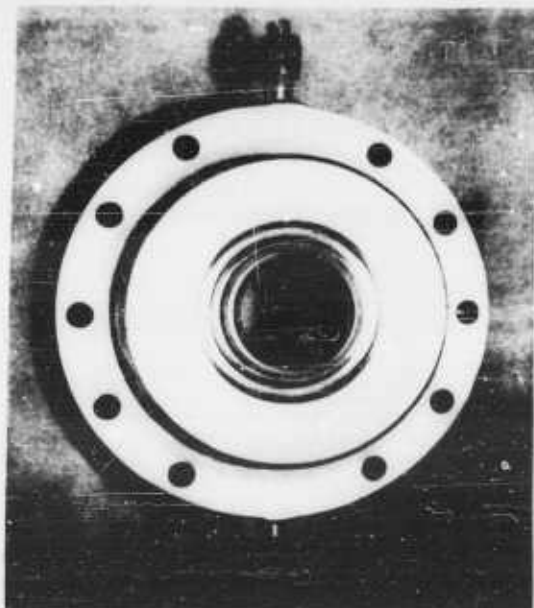
Figure 77. Graphitar G-39 Carbon Face,
AMS 350 Stainless Steel Bellows Seal -
Repeat Test
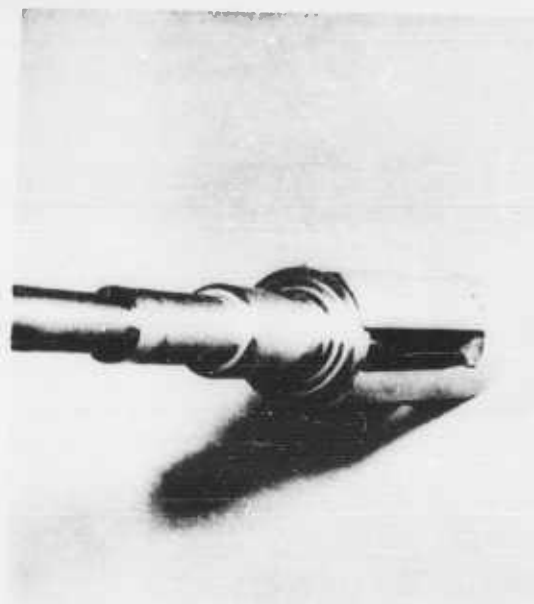
Figure 78. Type 316 Stainless Steel
Mating Ring - Repeat Test

Figure 79. Graphitar G-39 Carbon Face,
Butyl Rubber Packing Seal
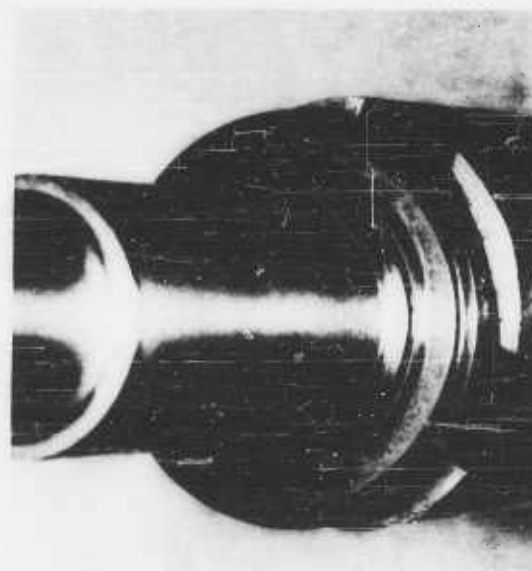
Figure 80. Nitralloy Mating Ring
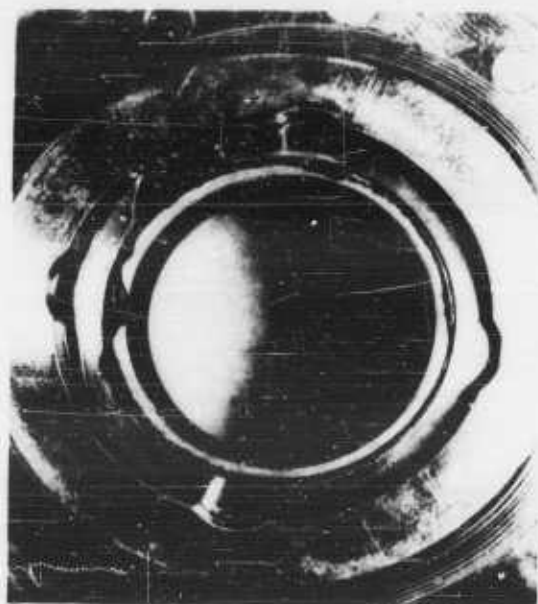
Figure 81. Butyl Rubber Packing
Seal After Test
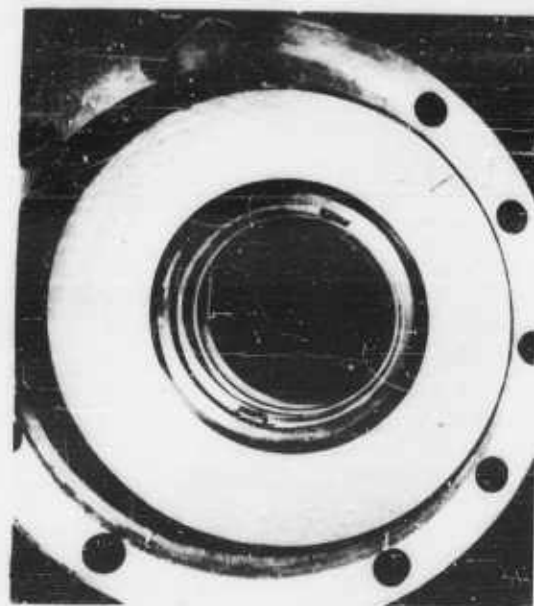
Figure 82. Graphitar G-39 Carbon Face
Anti-Rotation Locks, Type 410 Stainless
Steel Bellows

Figure 83. Type 316 Stainless Steel Mating Ring
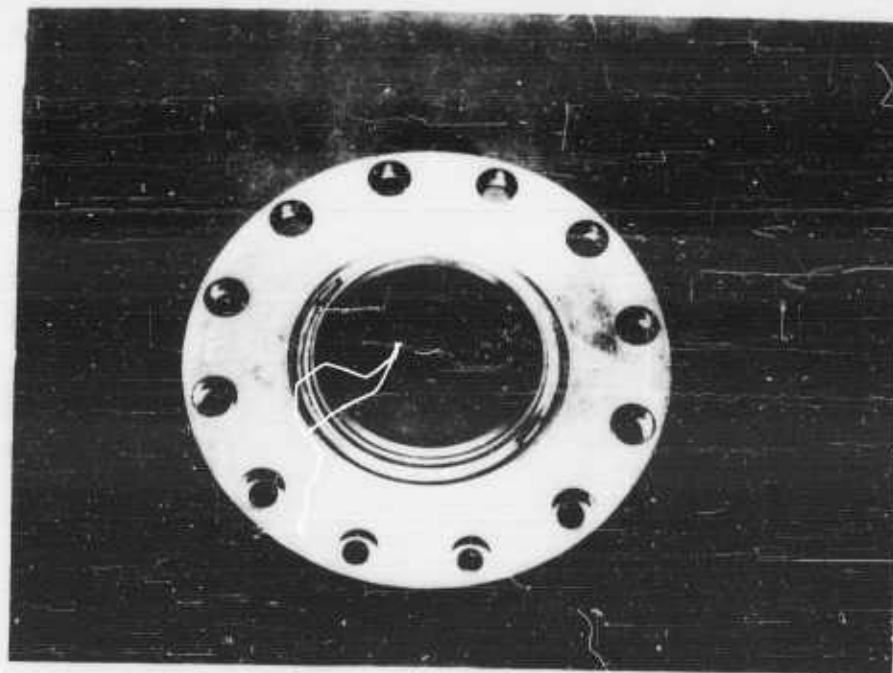
Figure 84. Graphitar G-39 Carbon Face 300 Series Stainless Steel
Cup and End Pieces and 410 Stainless Steel Bellows

Figure 85. Mating Ring - Chromium Carbide Flame Plated

Figure 86. Glass Impregnated Teflon Face, 300 Series Stainless Steel Cup and End Pieces and AM 350 Stainless Steel Bellows
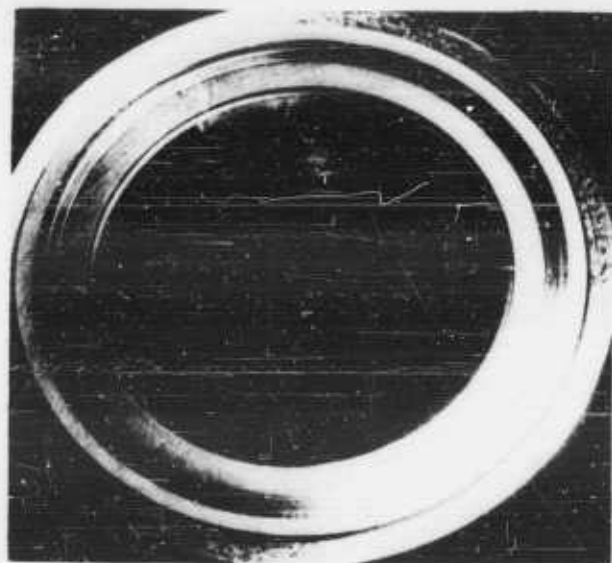
Figure 87. Type 316 Stainless Steel Mating Ring
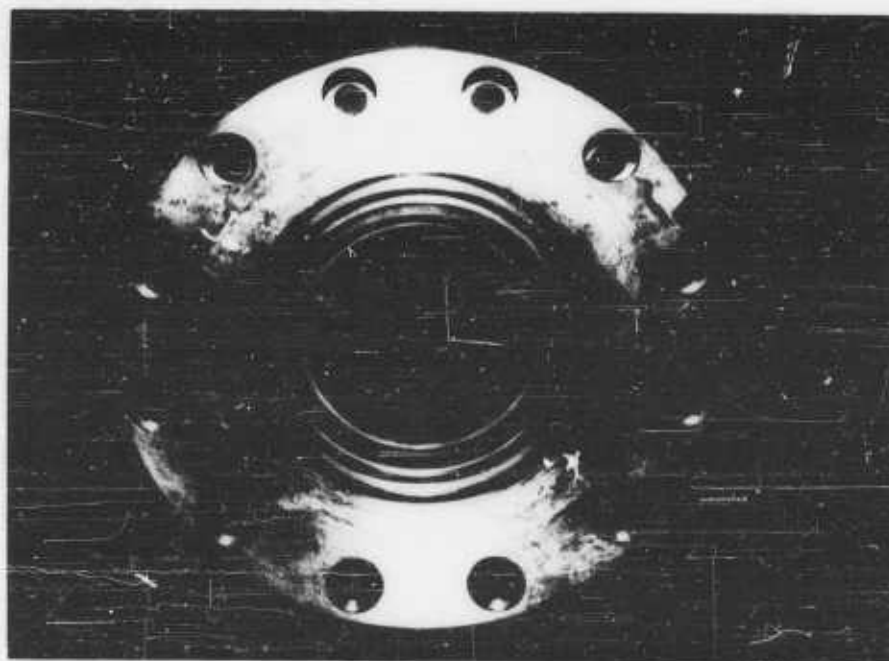
Figure 88. Glass Impregnated Teflon Face, 300 Series Stainless Steel Cup and End Pieces and Teflon Internal Packing
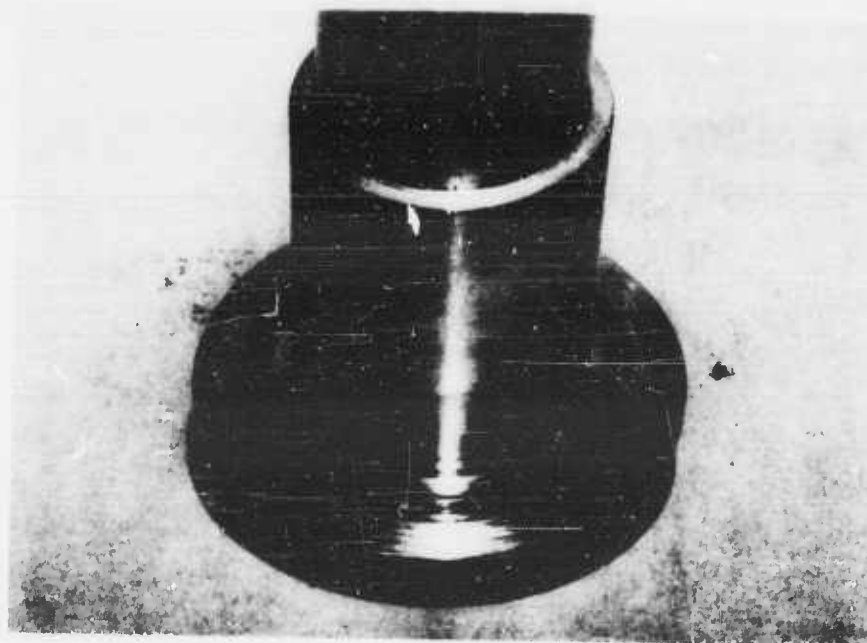
Figure 89. Type 316 Stainless Steel Mating Ring
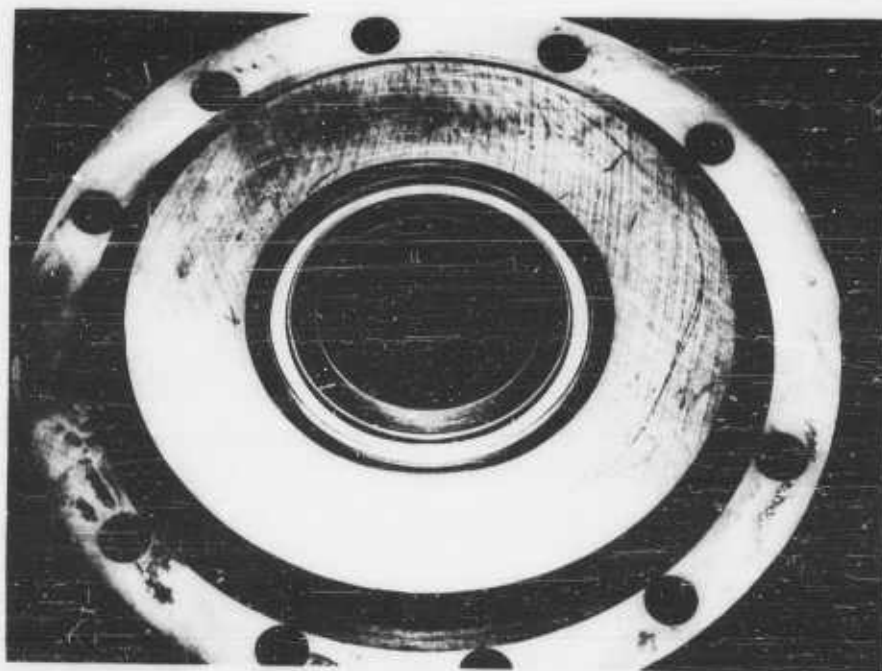
Figure 90. Glass Impregnated Teflon Face, 300 Series Stainless Steel
Cup and End Pieces and 347 Stainless Steel Bellows
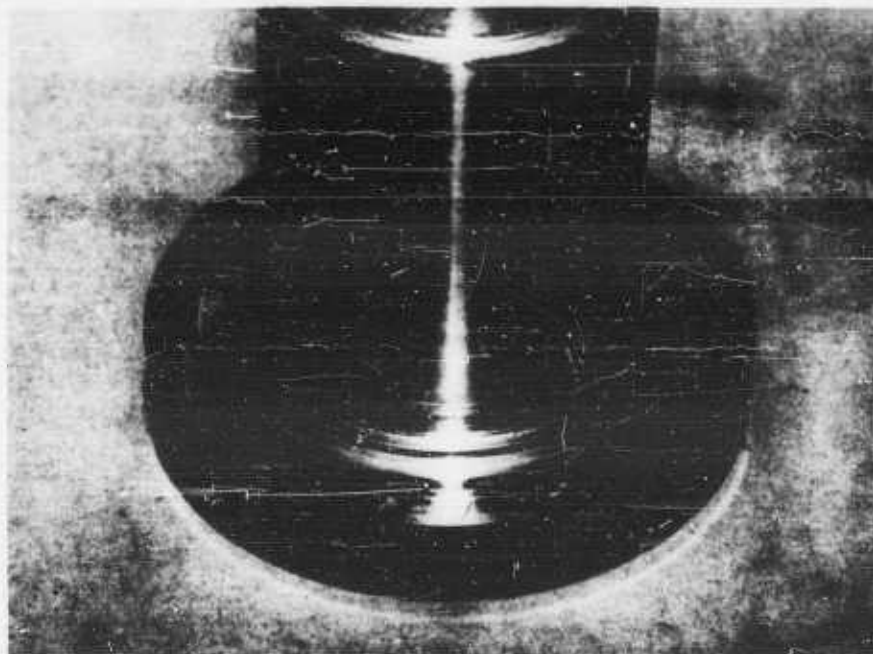
Figure 91. Type 316 Stainless Steel Mating Ring

Figure 92. Ball Bearing MRC 205-5 Races and Balls 440C Stainless
Steel Cage Machined and Riveted "S" Monel
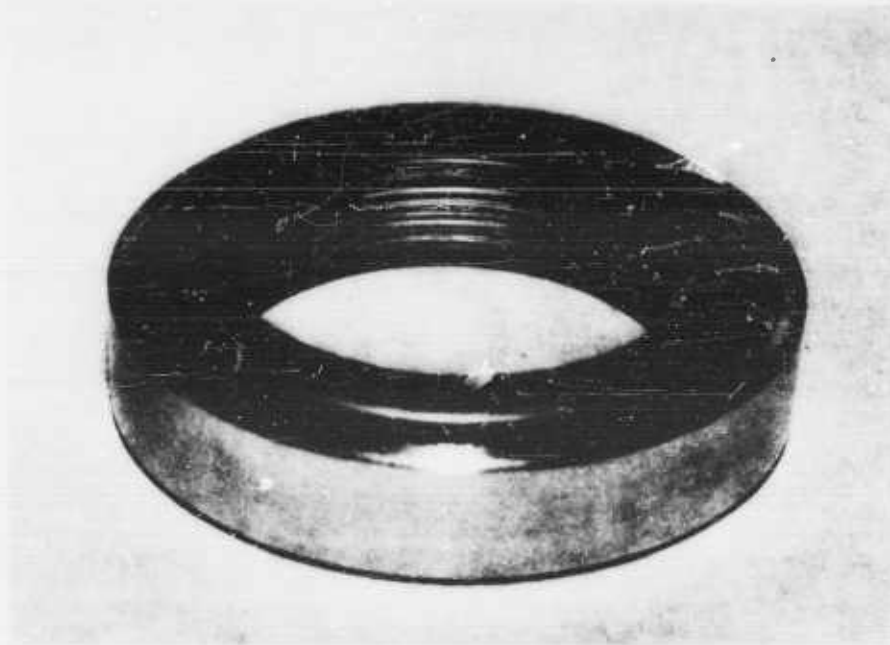
Figure 93. Graphitar G-39 Carbon Face, 300 Series Stainless Steel
Cup and End Pieces and AM 350 Stainless Steel Bellows
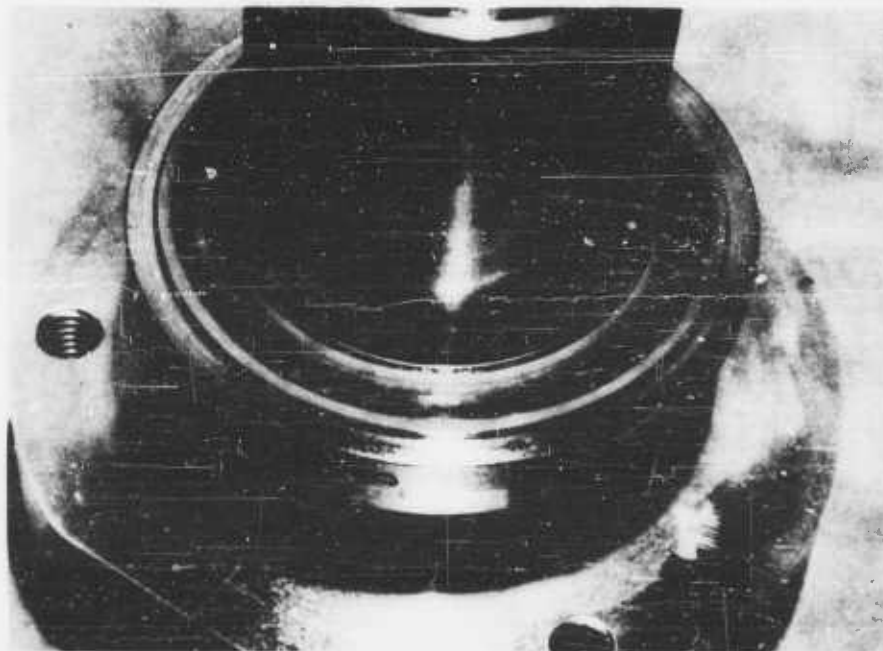
Figure 94. Type 316 Stainless Steel Mating Ring
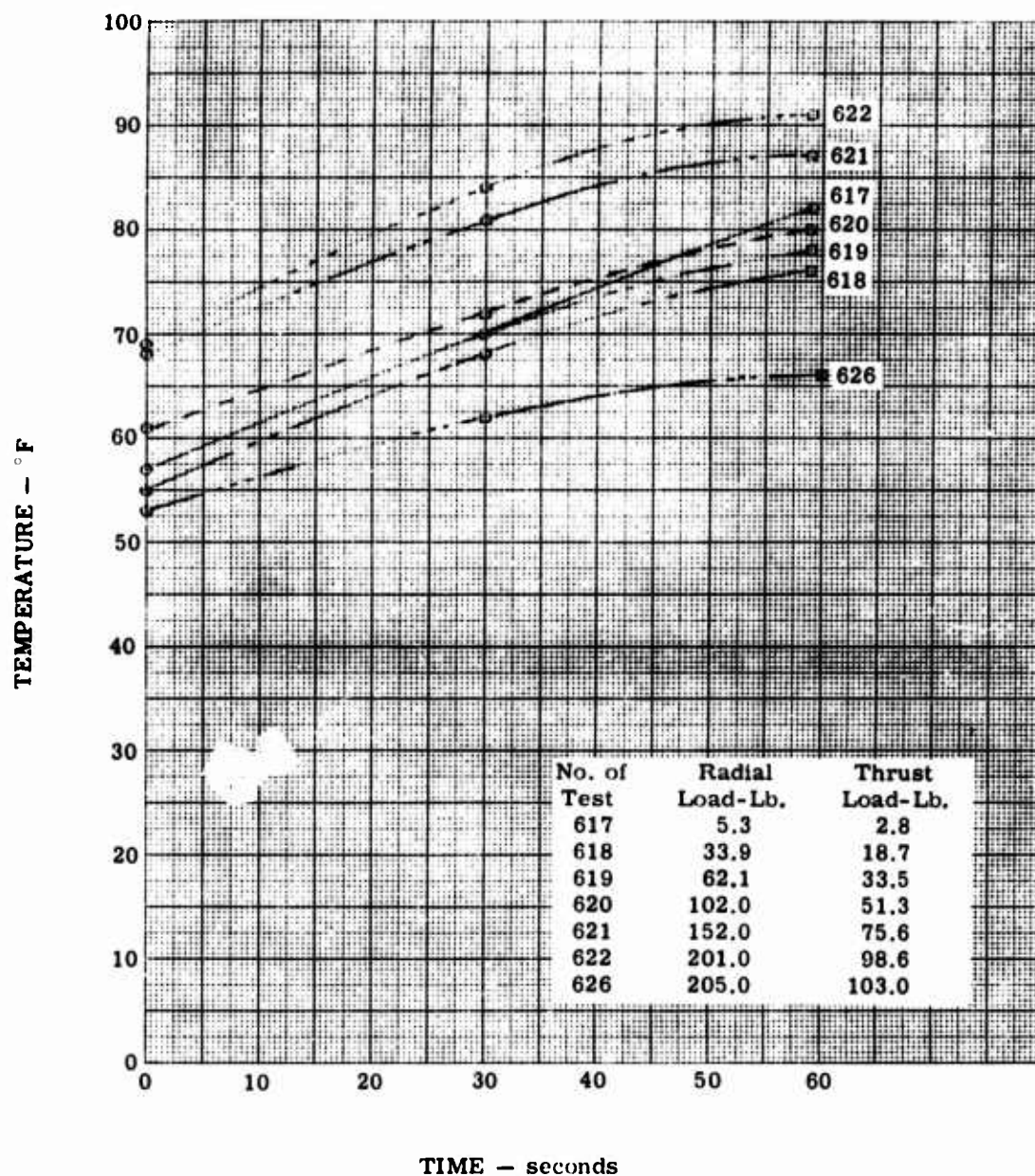
Figure 95. N₂O₄ Bearing Test, Test Bearing - MRC 205 Stainless Steel Ball Run No. 617-622 and Run No. 626

The chart plots TEMPERATURE – °F (y-axis, 0 to 100) versus TIME – seconds (x-axis, 0 to 60) with curves labeled 622, 621, 617, 620, 619, 618, and 626.

No. of Test	Radial Load-Lb.	Thrust Load-Lb.
617	5.3	2.8
618	33.9	18.7
619	62.1	33.5
620	102.0	51.3
621	152.0	75.6
622	201.0	98.6
626	205.0	103.0

TEMPERATURE – °F

TIME – ninutes

No. of Test	Radial Load-Lb.	Thrust Load-Lb.
623	206	103
624	203	101.4
625	203	100.64
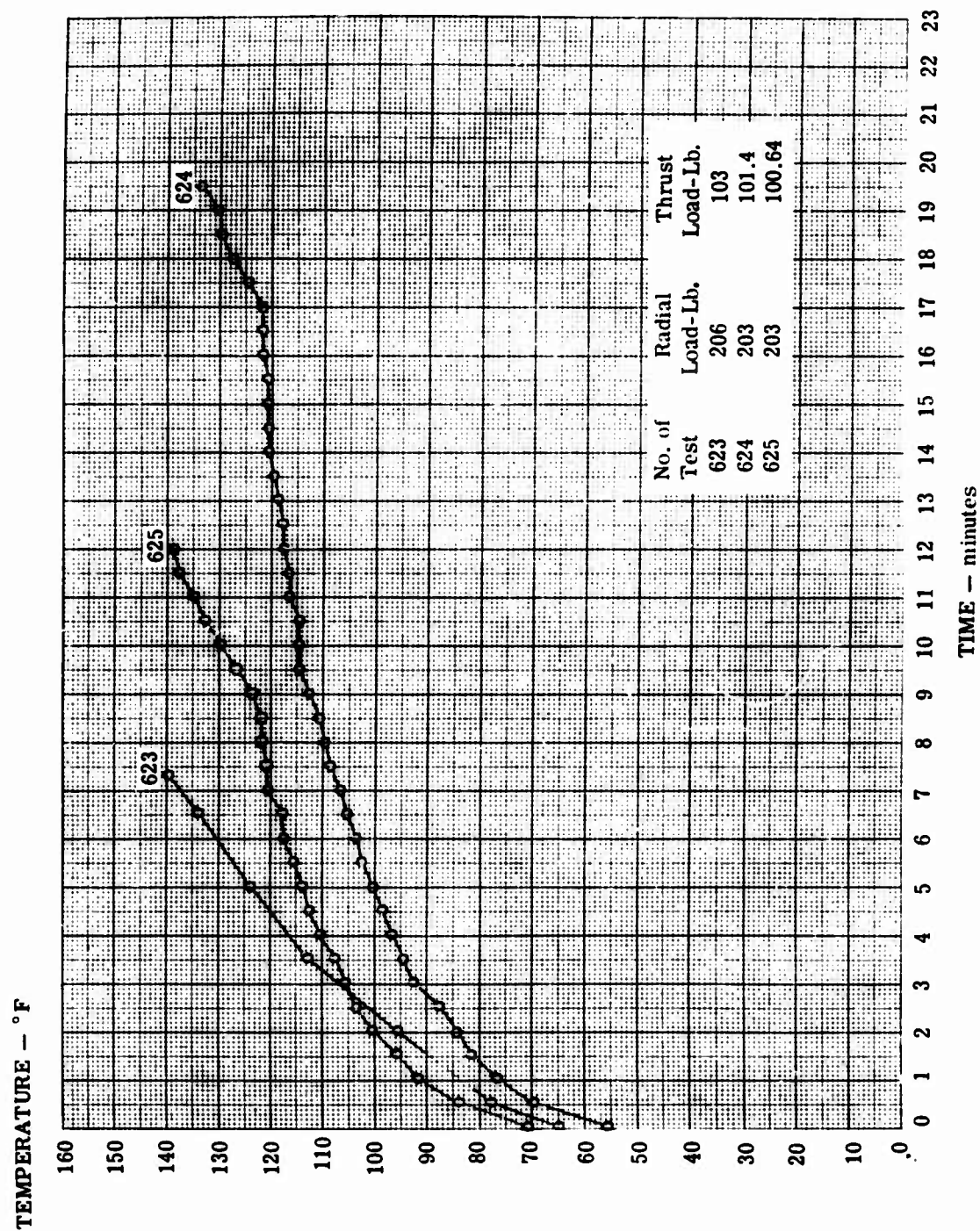
Figure 96. N_2O_4 Bearing Test, Run No. 623-625
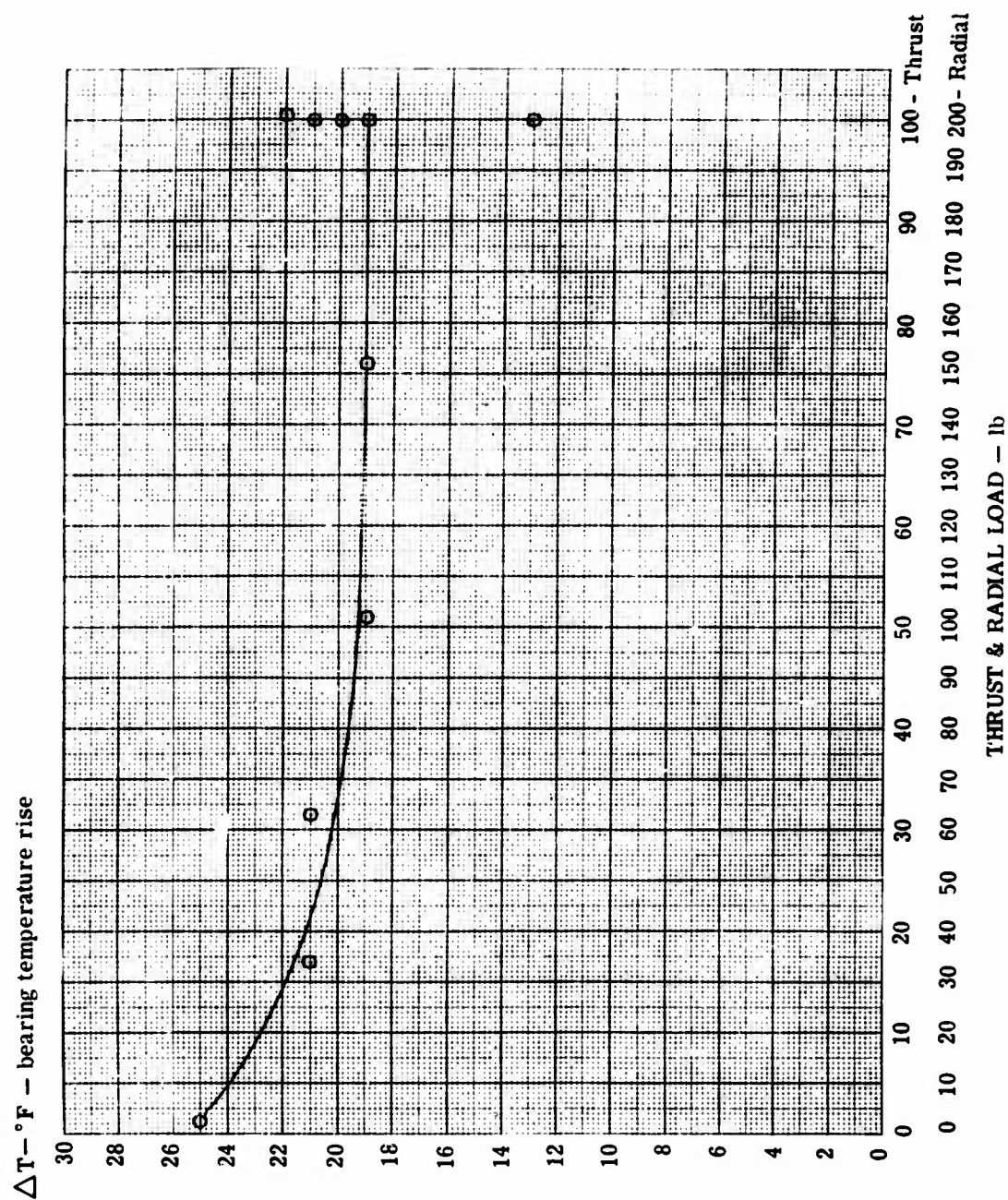
Figure 97. N_2O_4 Bearing Test
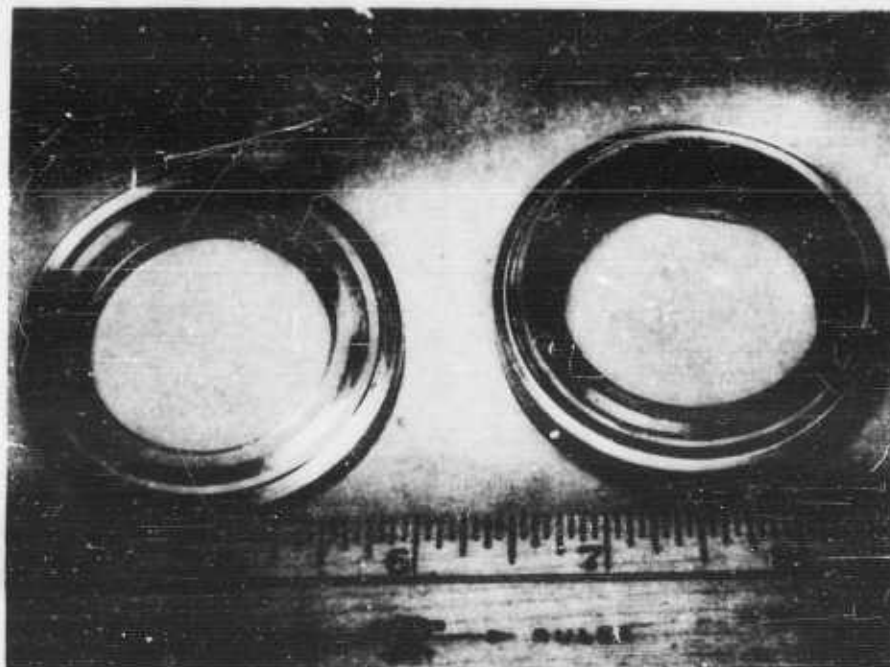
Figure 98. Sleeve Bearing - Glass Impregnated Teflon
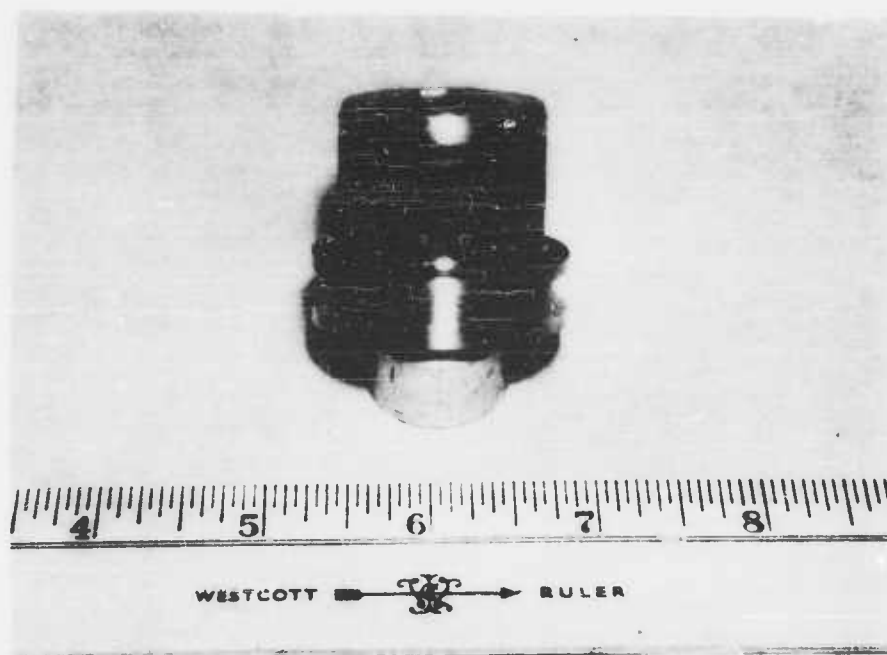
Figure 99. Sleeve Bearing Shaft - Type 316 Stainless Steel

No. of Test	Radial Load Lb.	Propellant Pressure - Psig	Bleed Orifice Dia. Inches	Comments
627	1.4	85	.020	
628	33.5	85	.020	
629	66.8	85	.020	
630	103.0	85	.020	Plugged
631	103.0	85	.025	Orifice
632	102.0	85	.025	"
633	165.0	130	.025	"
634	162.0	130	.025	"
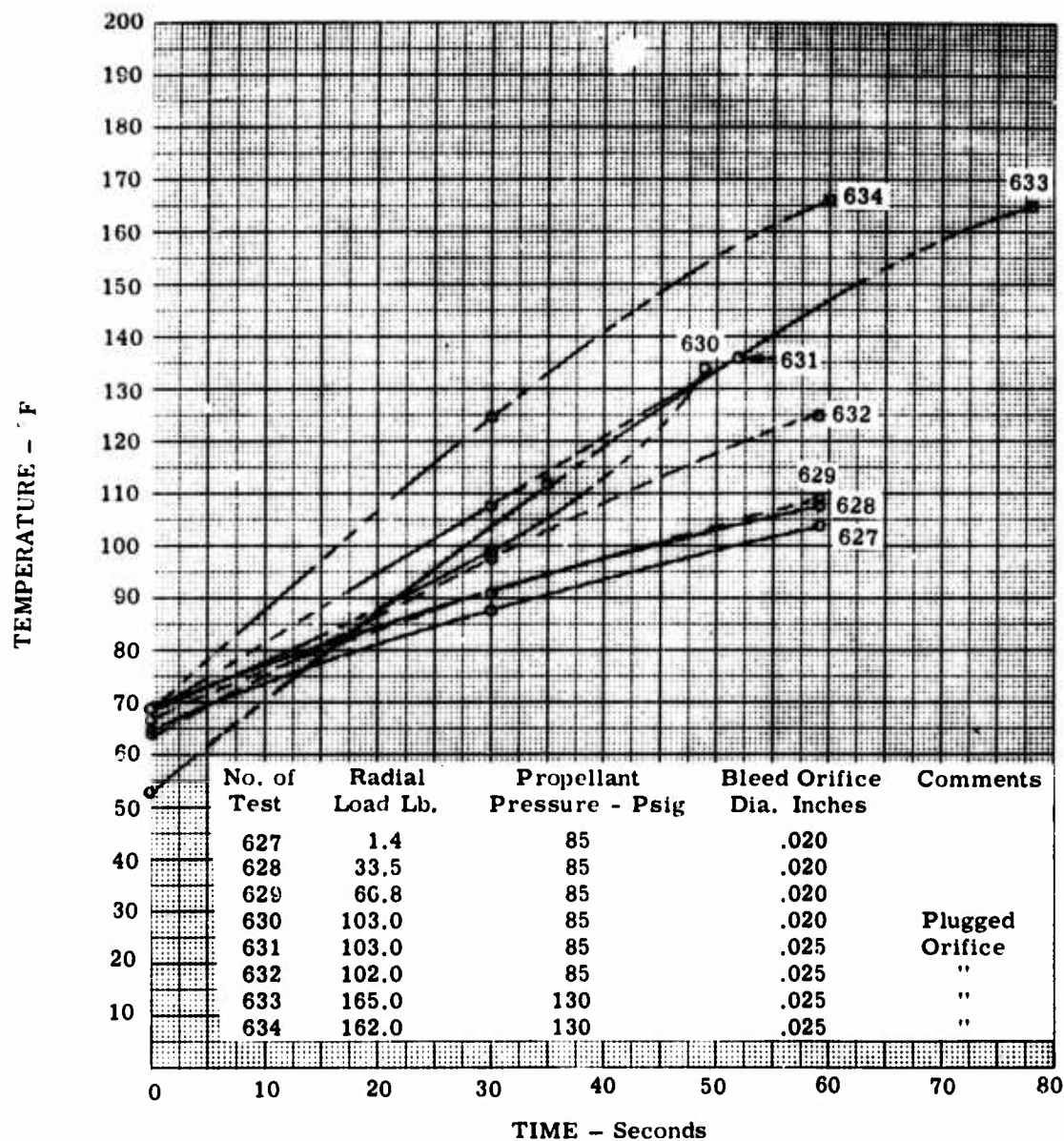
Figure 100. N_2O_4 Bearing Test, Run No. 627-634
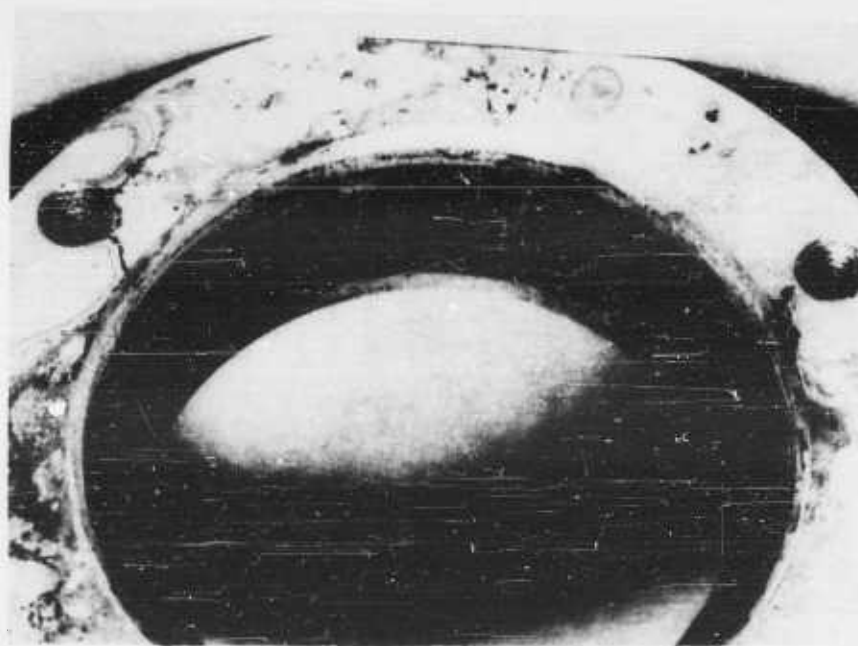
Figure 101. MCR 205-C Roller Bearing Outer Race - SAE 52100 Steel
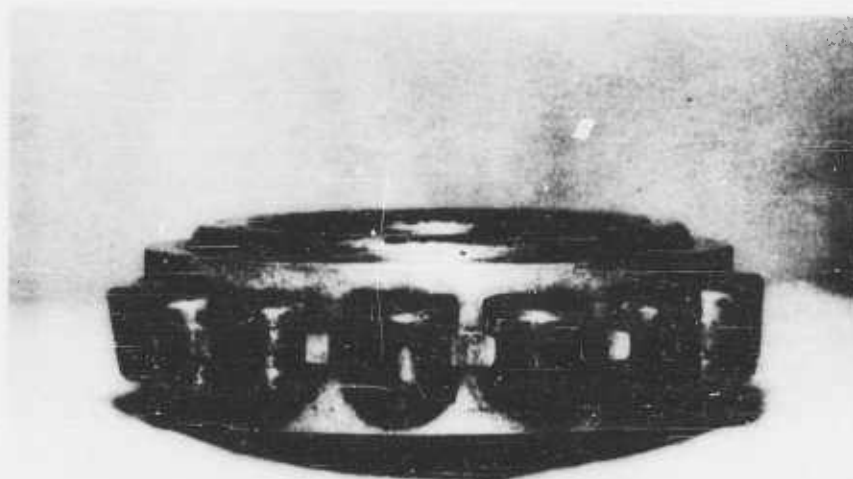
Figure 102. MRC 205-C Roller Bearing - Inner Race and Rollers
SAE 52100 Steel and Cage - Bronze

Figure 103. Purebon Carbon 658 RC Face 300 Series Stainless
Steel Cup and End Pieces and Inconel-X Bellows
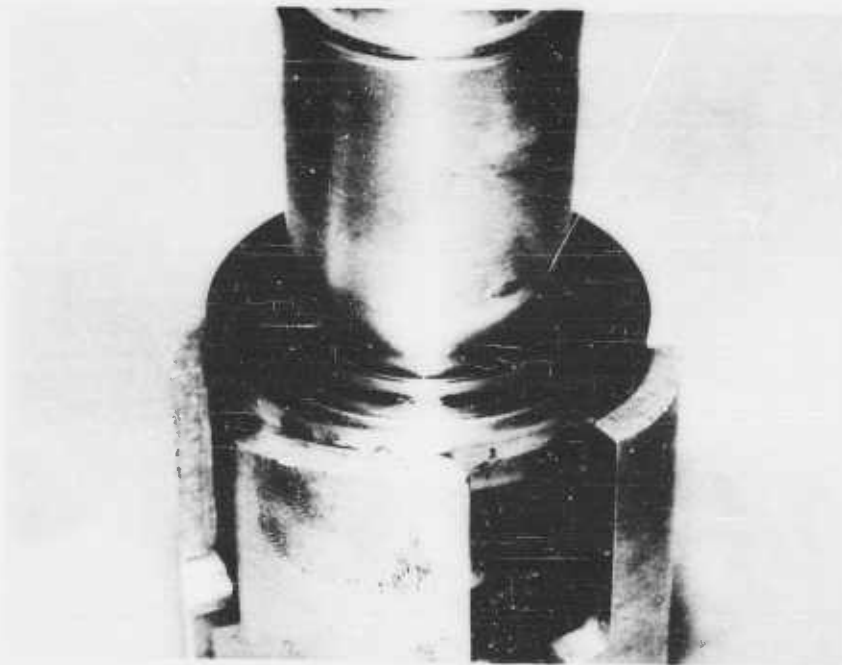
Figure 104. Type 316 Stainless Steel Mating Ring
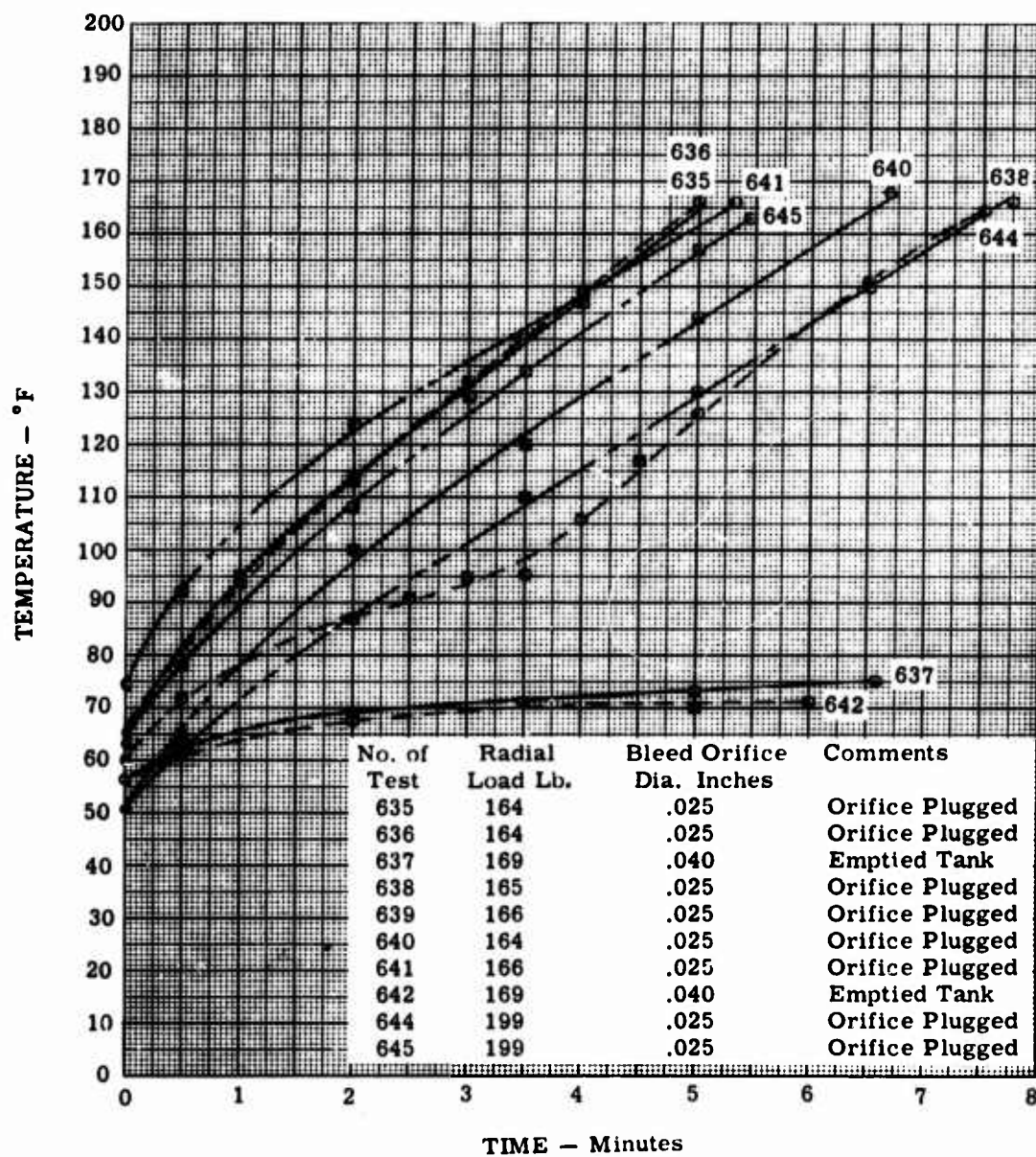
Figure 105. N₂O₄ Bearing Test, Run No. 635-642 and Run No. 644-645

The following table appears within the figure:

No. of Test	Radial Load Lb.	Bleed Orifice Dia. Inches	Comments
635	164	.025	Orifice Plugged
636	164	.025	Orifice Plugged
637	169	.040	Emptied Tank
638	165	.025	Orifice Plugged
639	166	.025	Orifice Plugged
640	164	.025	Orifice Plugged
641	166	.025	Orifice Plugged
642	169	.040	Emptied Tank
644	199	.025	Orifice Plugged
645	199	.025	Orifice Plugged

TIME – Minutes

Figure 106. N_2O_4 Bearing Test - Run No. 643

TEMPERATURE – °F
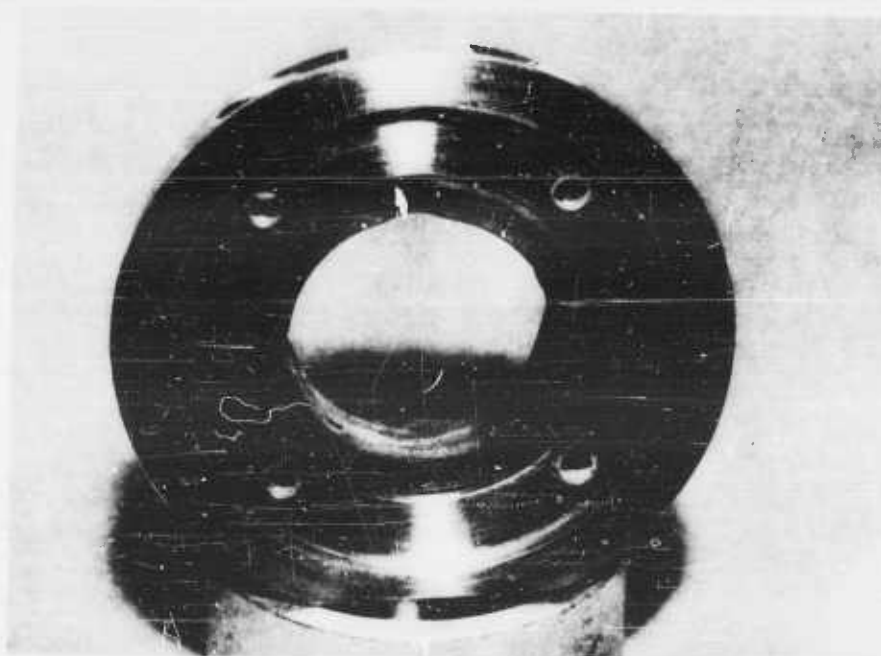
Figure 107. Sleeve Bearing - Graphite Impregnated Teflon
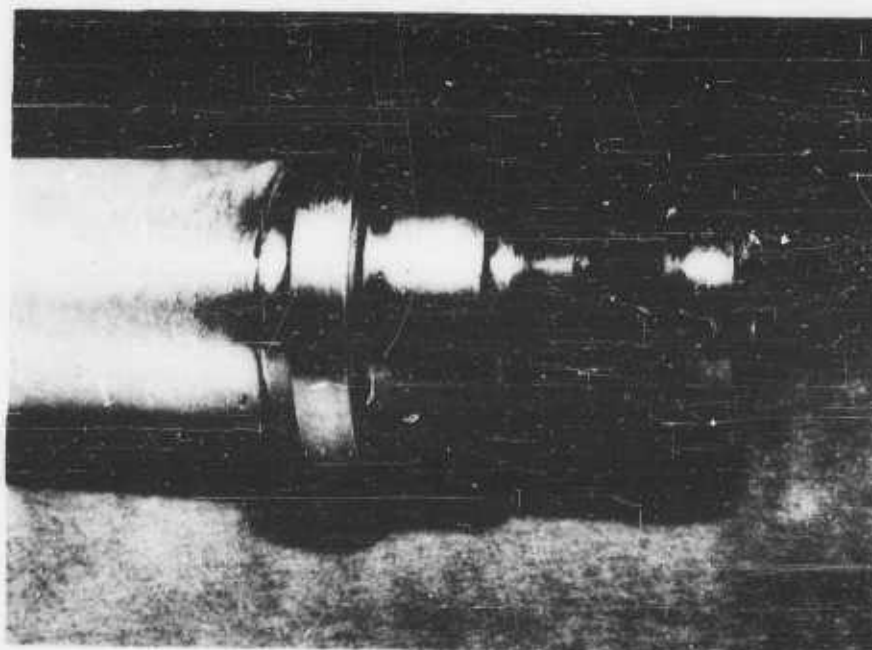
Figure 108. Sleeve Bearing Shaft - Type 316 Stainless Steel

Figure 109. Graphitar G-39 Carbon Face - Anti-Rotation Locks
Type 410 Stainless Steel Bellows

Figure 110. Type 316 Stainless Steel Mating Ring

No. of Test	Radial Load Lb.	Bleed Orifice Dia. Inches	Comments
646	204.5	.025	Plugged Orifice
647	197.6	.040	Plugged Orifice
648	204.1	.040	Emptied Tank
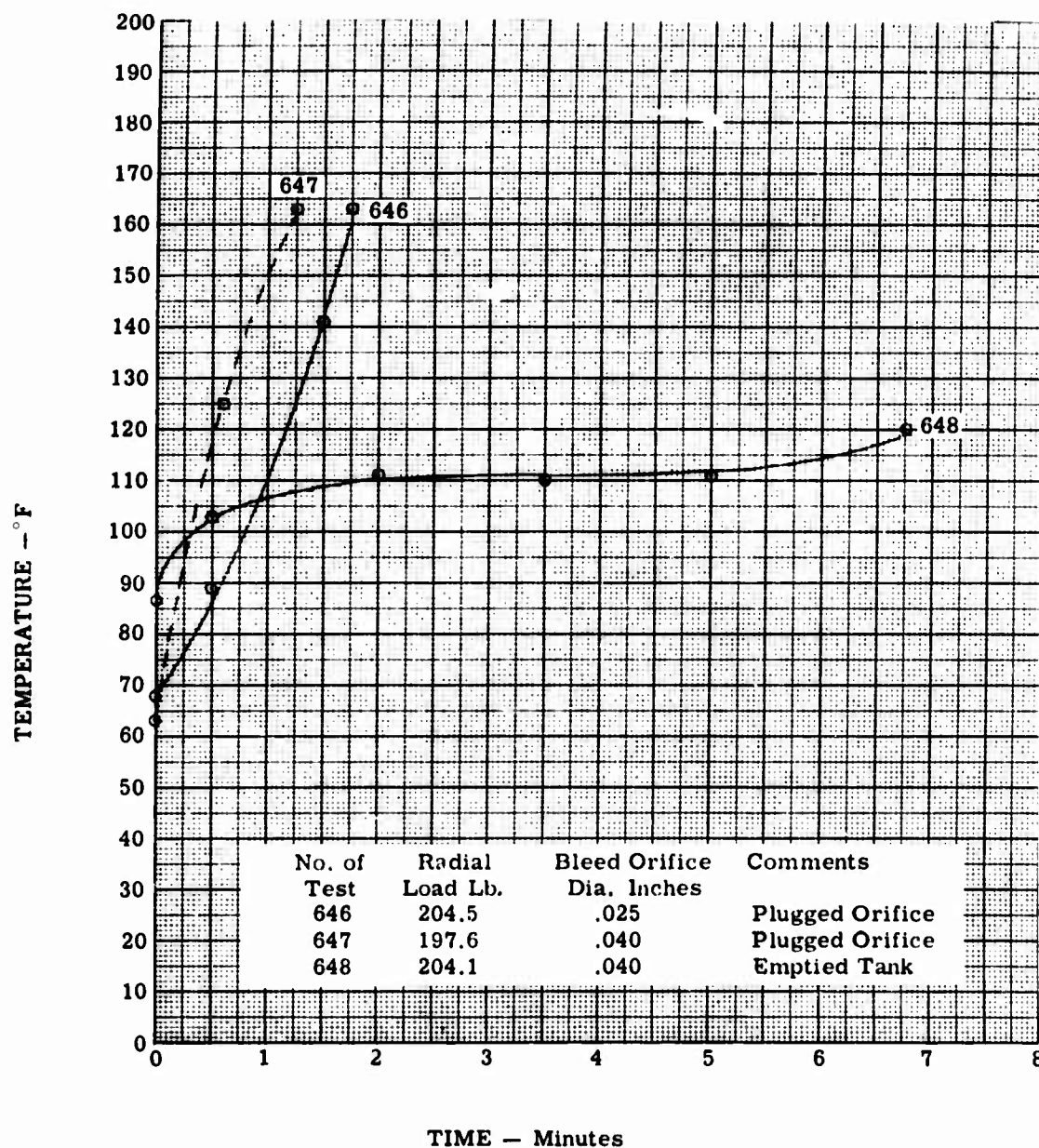
Figure 111. N$_2$O$_4$ Bearing Test, Run No. 646-648

Figure 112. Fuel Pump Impeller

Figure 113. Plot of Cavitation Characteristics of UDMH Fuel Pump

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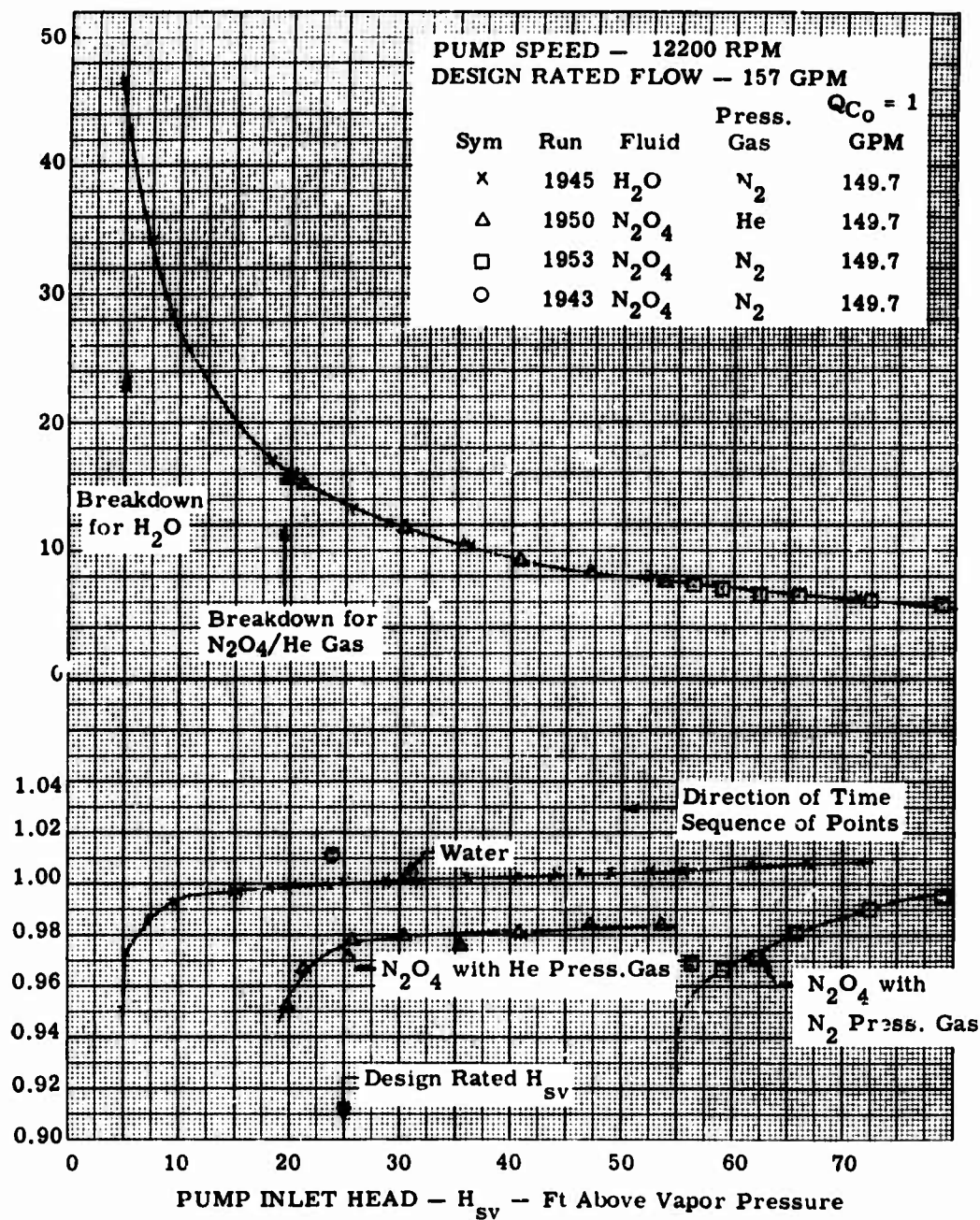
Figure 114. Cavitation Characteristic of Model 8096 Oxidizer Pump
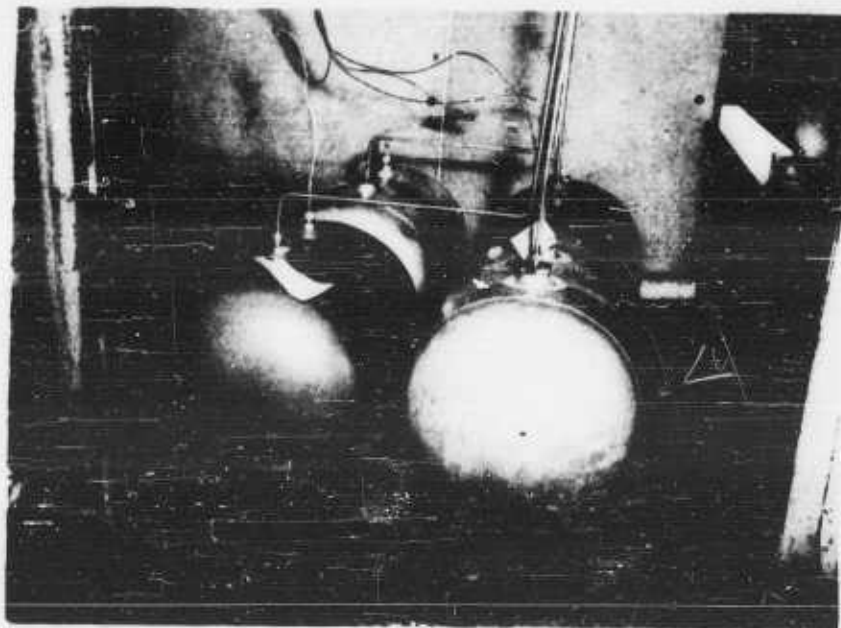
Figure 115. Fuel Storage Tanks at 160° F
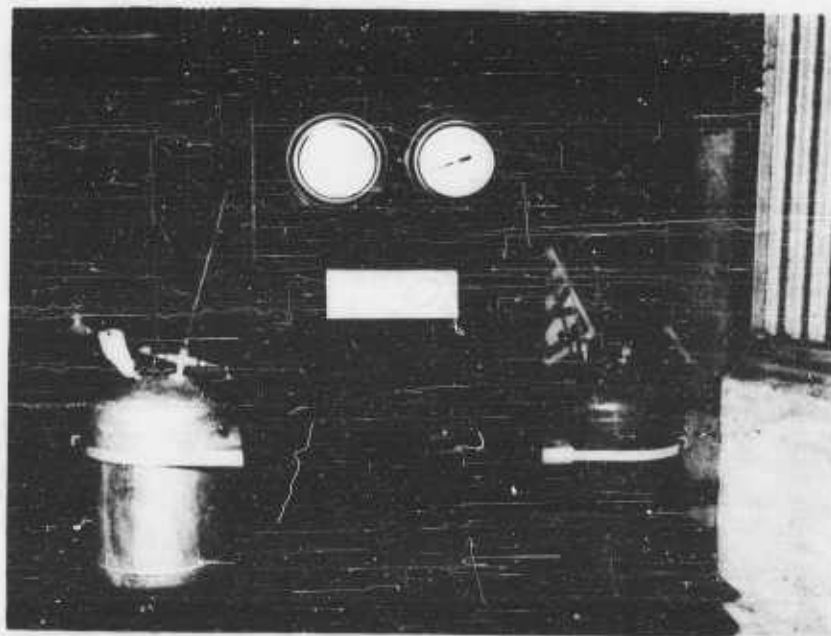
Figure 116. Oxidizer Storage Tanks at 70° F

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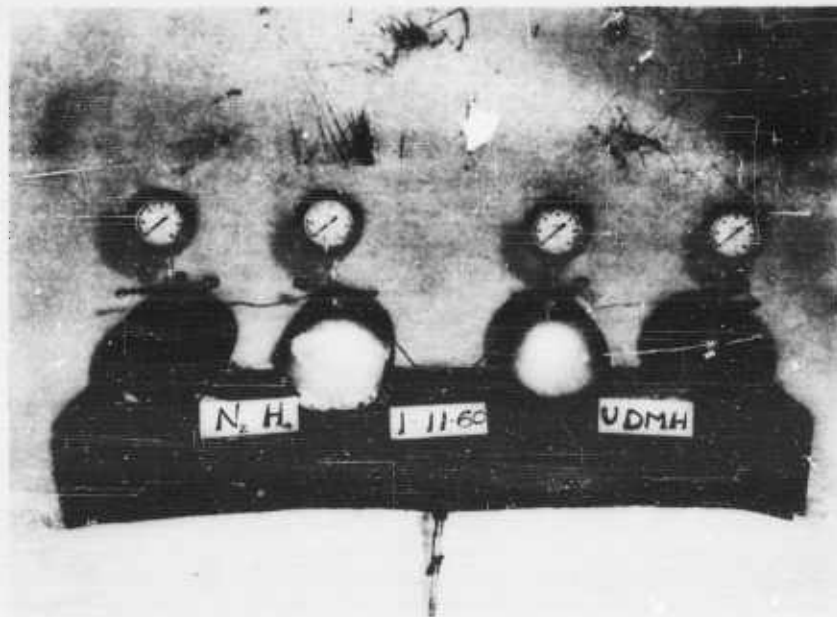
Figure 117. Fuel Storage Tanks at Outdoor Temperature
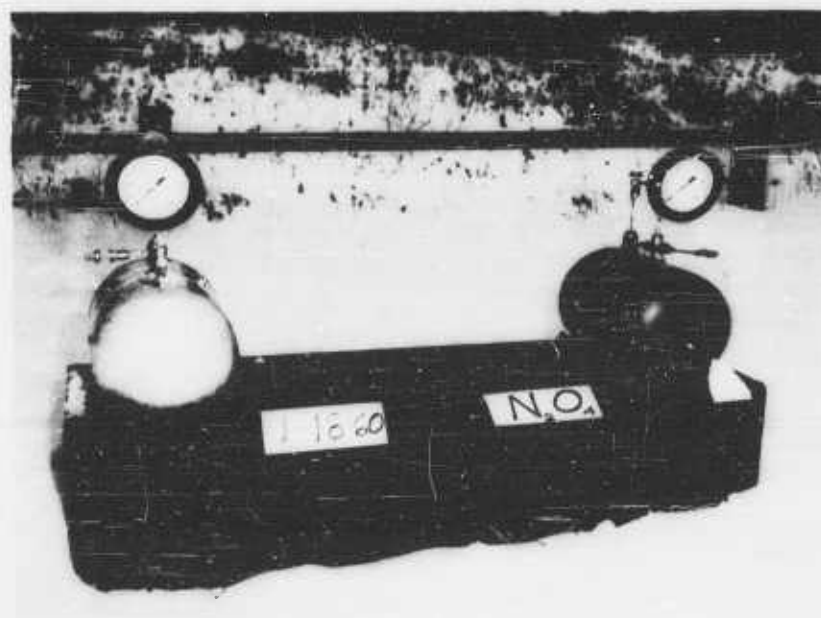
Figure 118. Oxidizer Storage Tanks at Outdoor Temperature
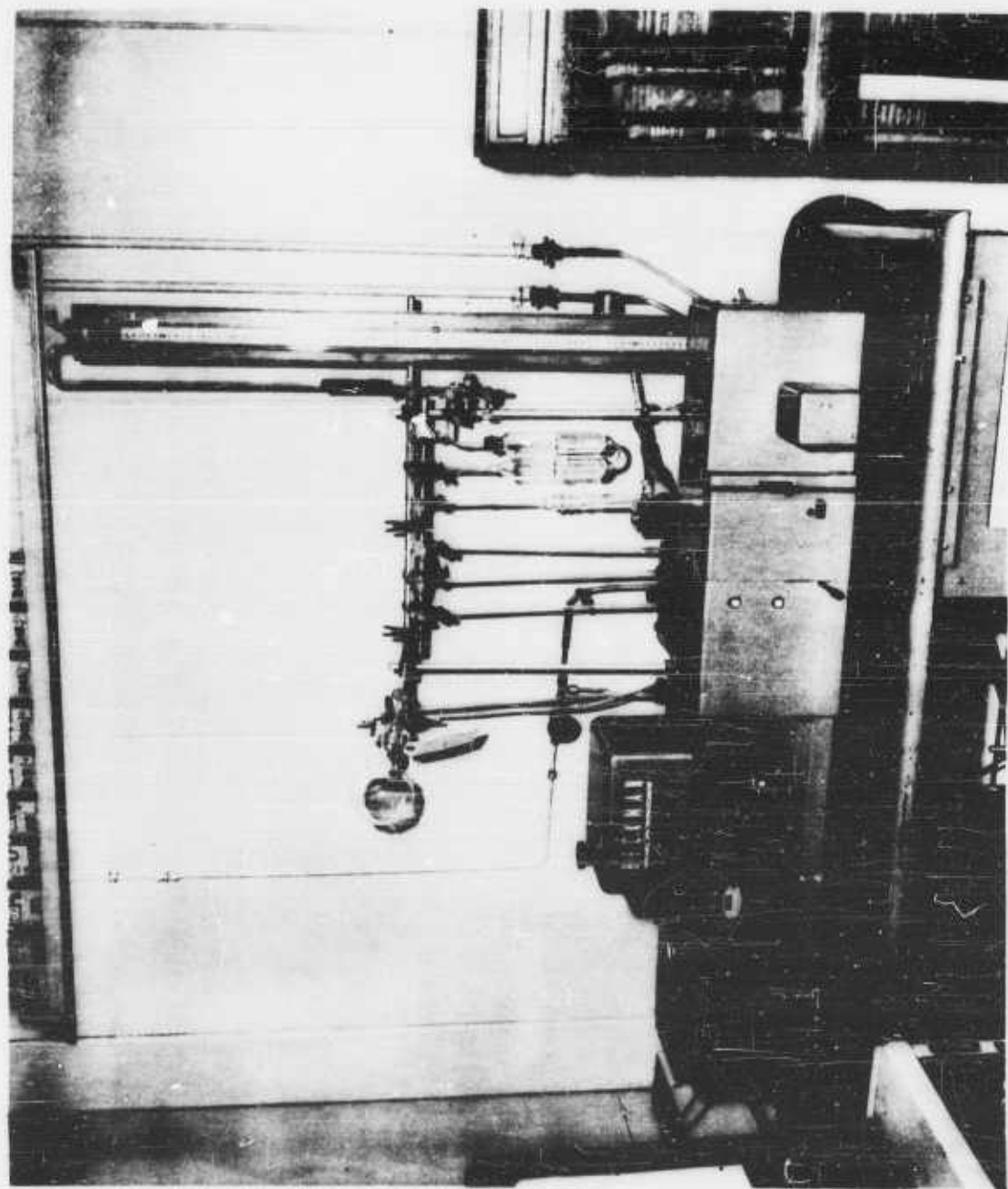
Figure 119. Gas Handling Train and Infrared Spectrophotometer

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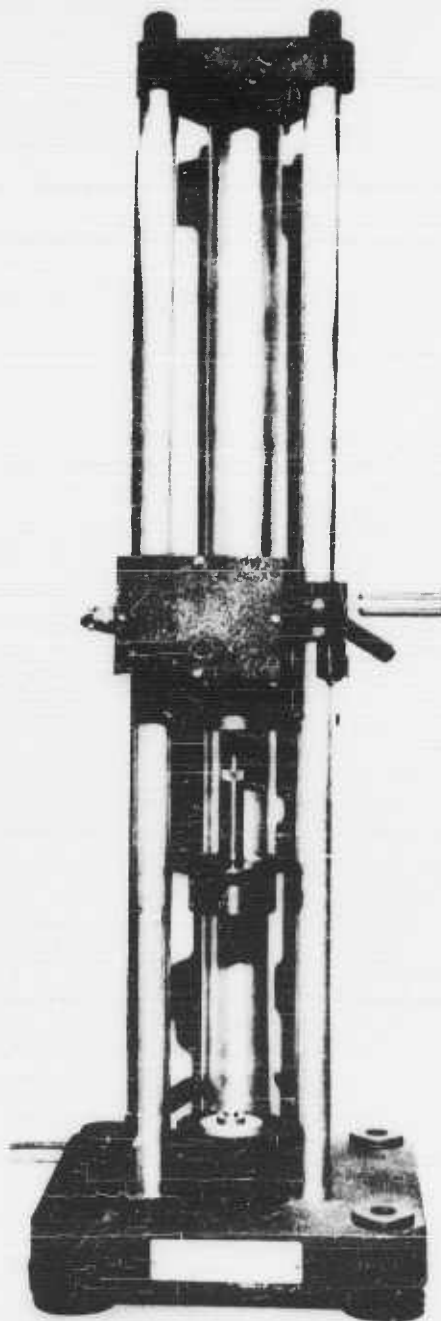
Figure 120. Impact Sensitivity Tester
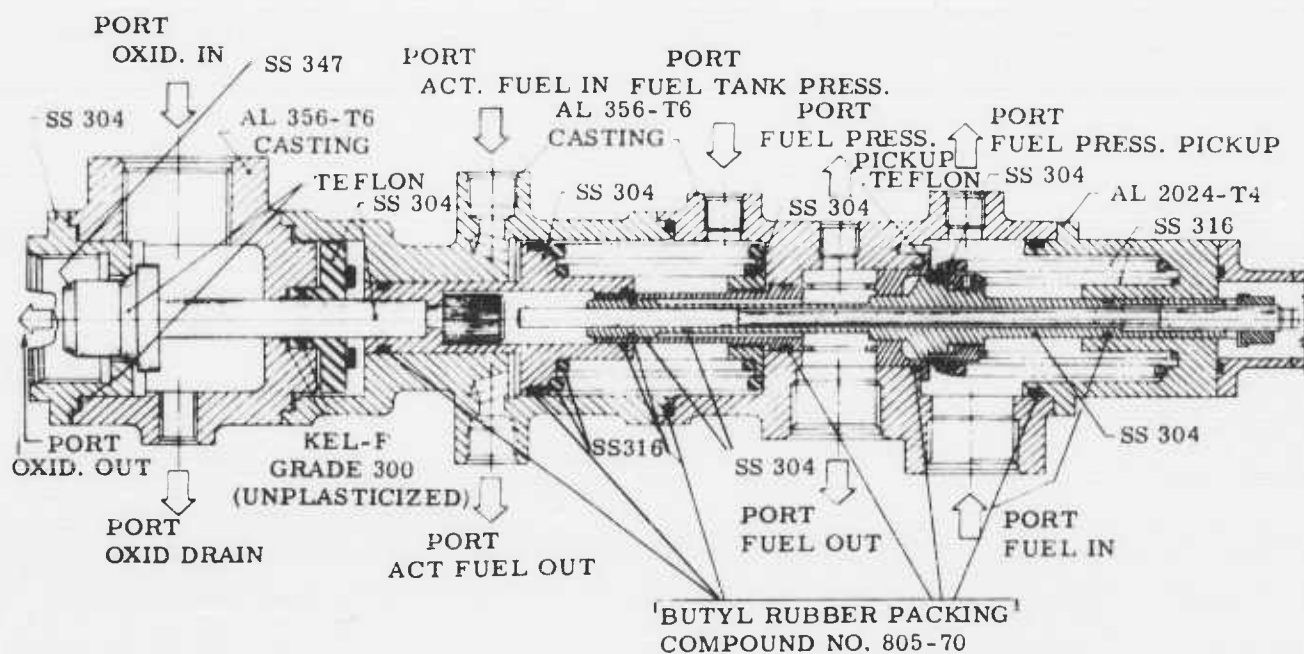
Figure 121. Cross Section-Valve Assembly - Propellant, Thrust Chamber 62-472-163
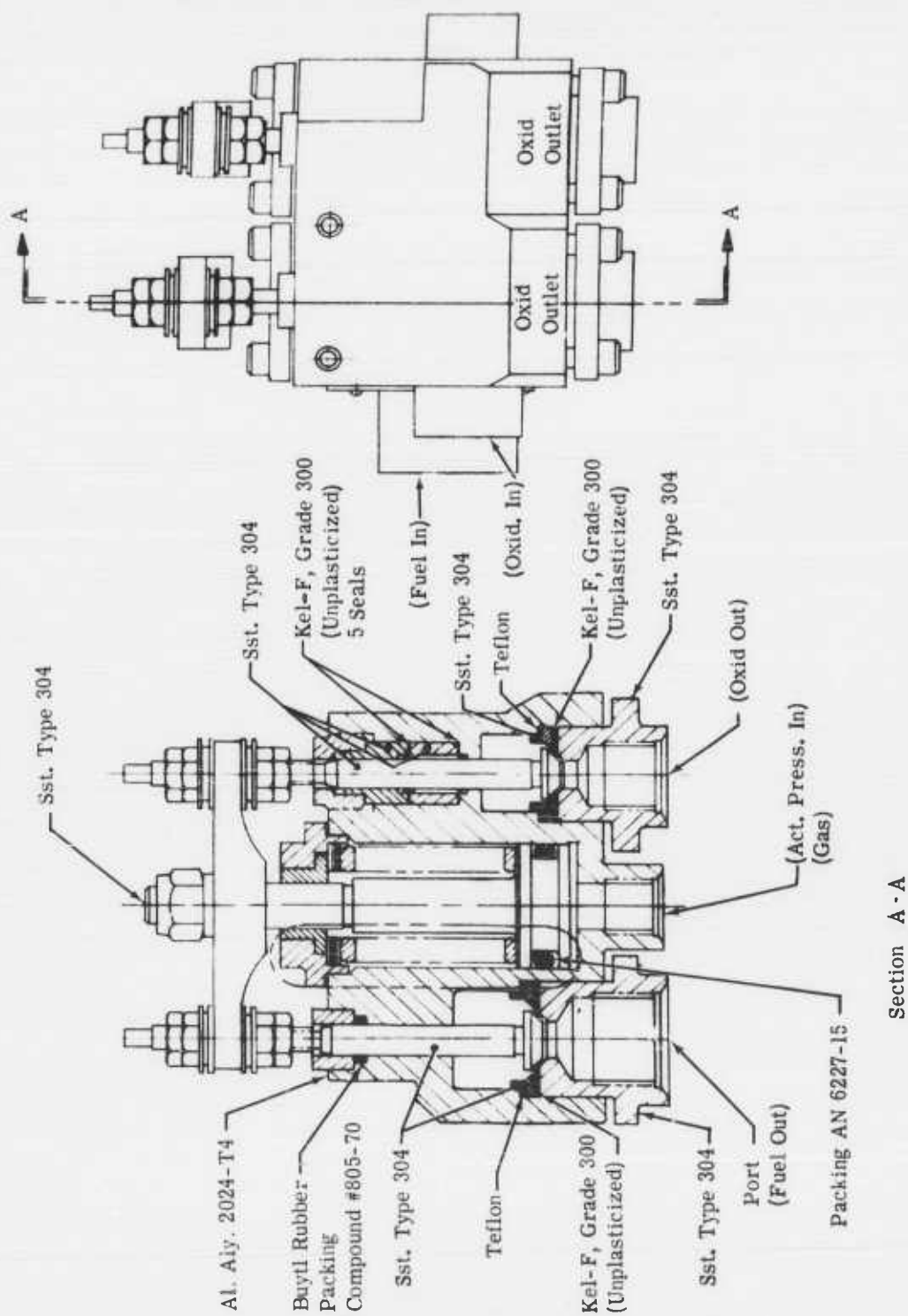
Section A - A

Figure 122. Cross Section - Valve Assembly - Propellant, Igniter and Gas Generator 62-472-367
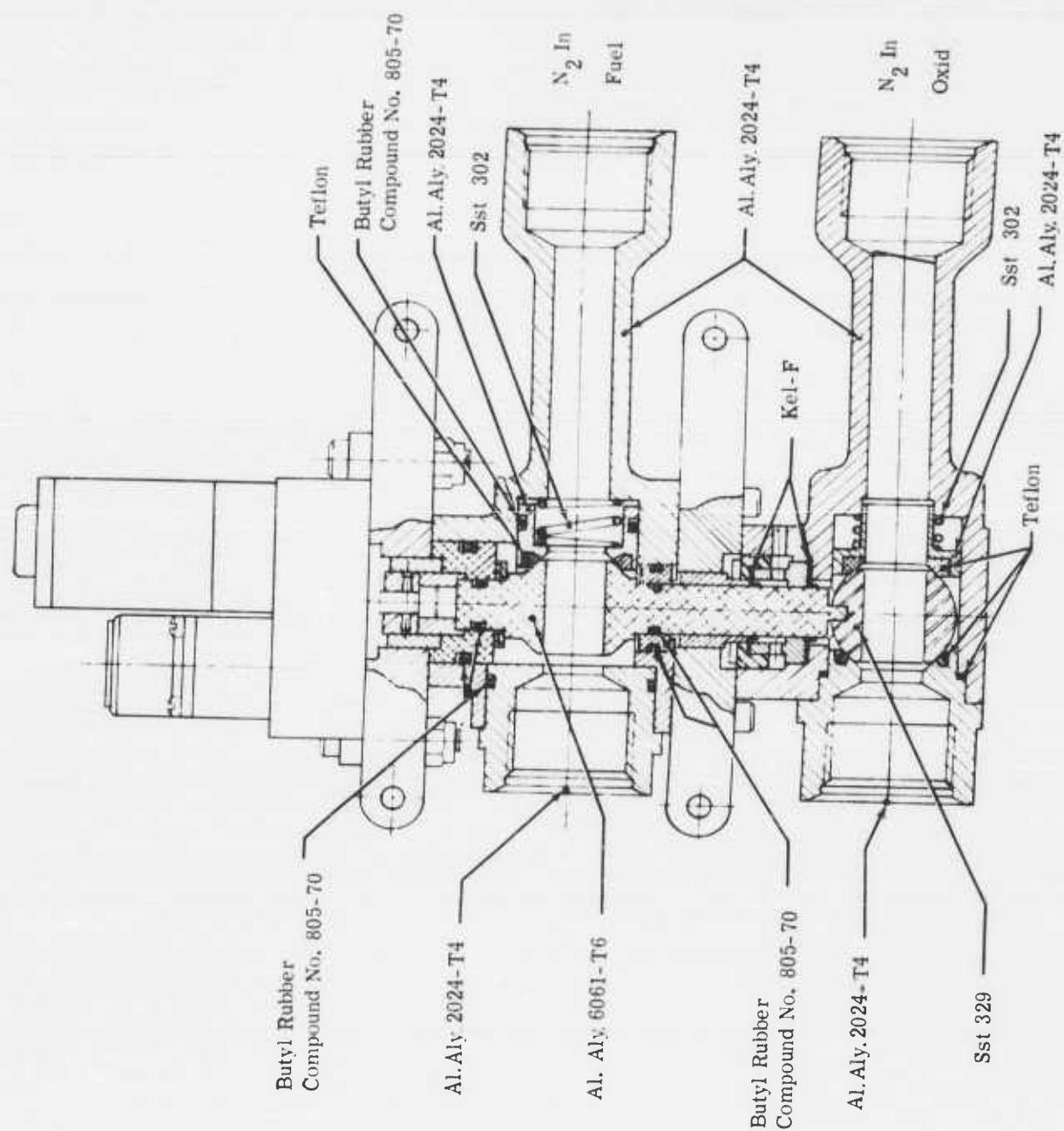
Figure 123. Cross Section - Valve - Dual 2-Way P/N 83 B/P No. 200834

Teflon

Butyl Rubber
Compound No. 805-70

Al. Aly. 2024-T4

Sst 302

N₂ In

Fuel

Al. Aly. 2024-T4

Al. Aly. 2024-T4

N₂ In

Oxid

Kel-F

Sst 302

Al. Aly. 2024-T4

Teflon

Butyl Rubber
Compound No. 805-70

Al. Aly. 2024-T4

Al. Aly. 6061-T6

Butyl Rubber
Compound No. 805-70

Al. Aly. 2024-T4

Sst 329
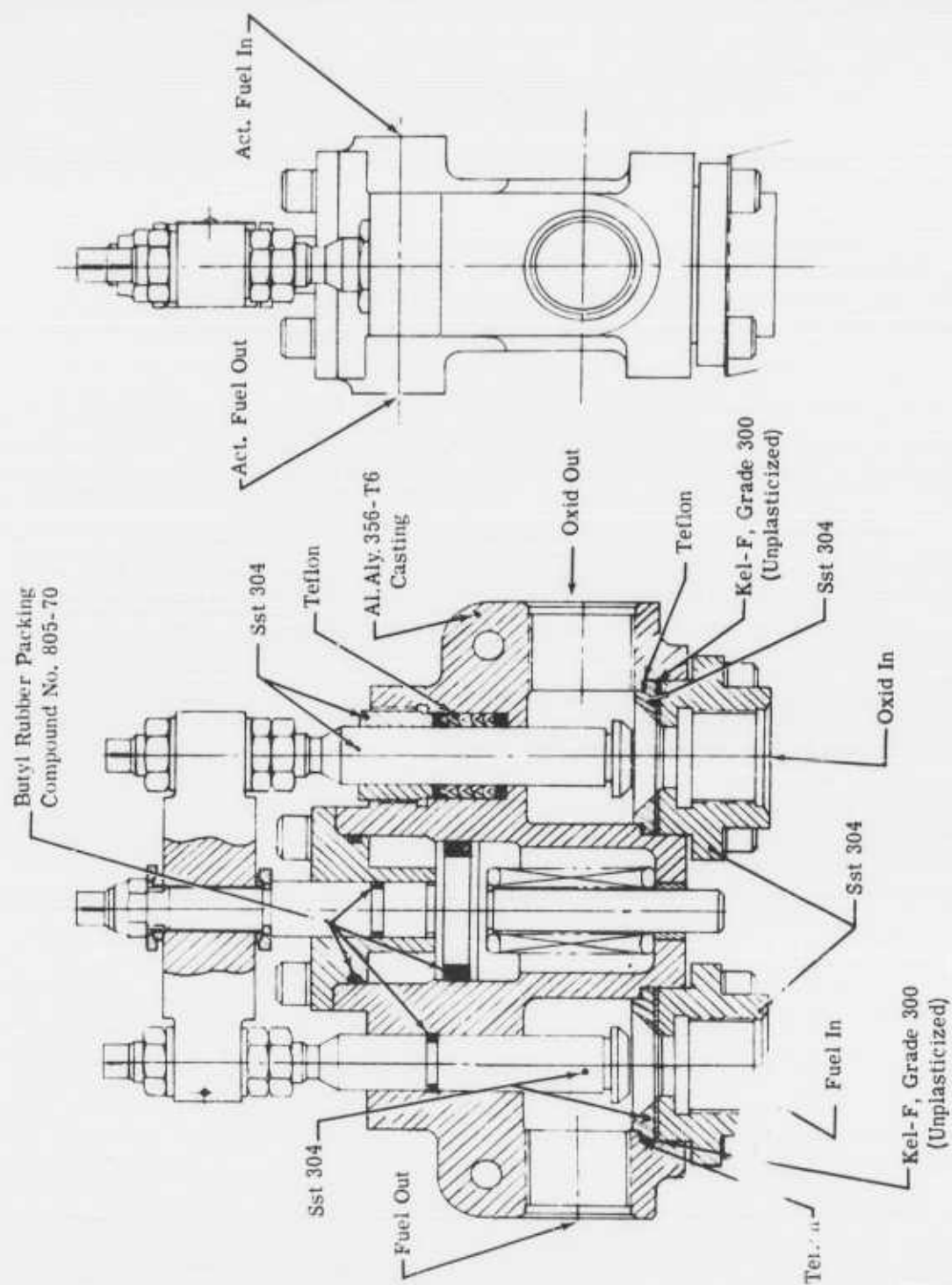
Figure 124. Cross Section – Valve Assembly Bypass Turbine 62-472-213
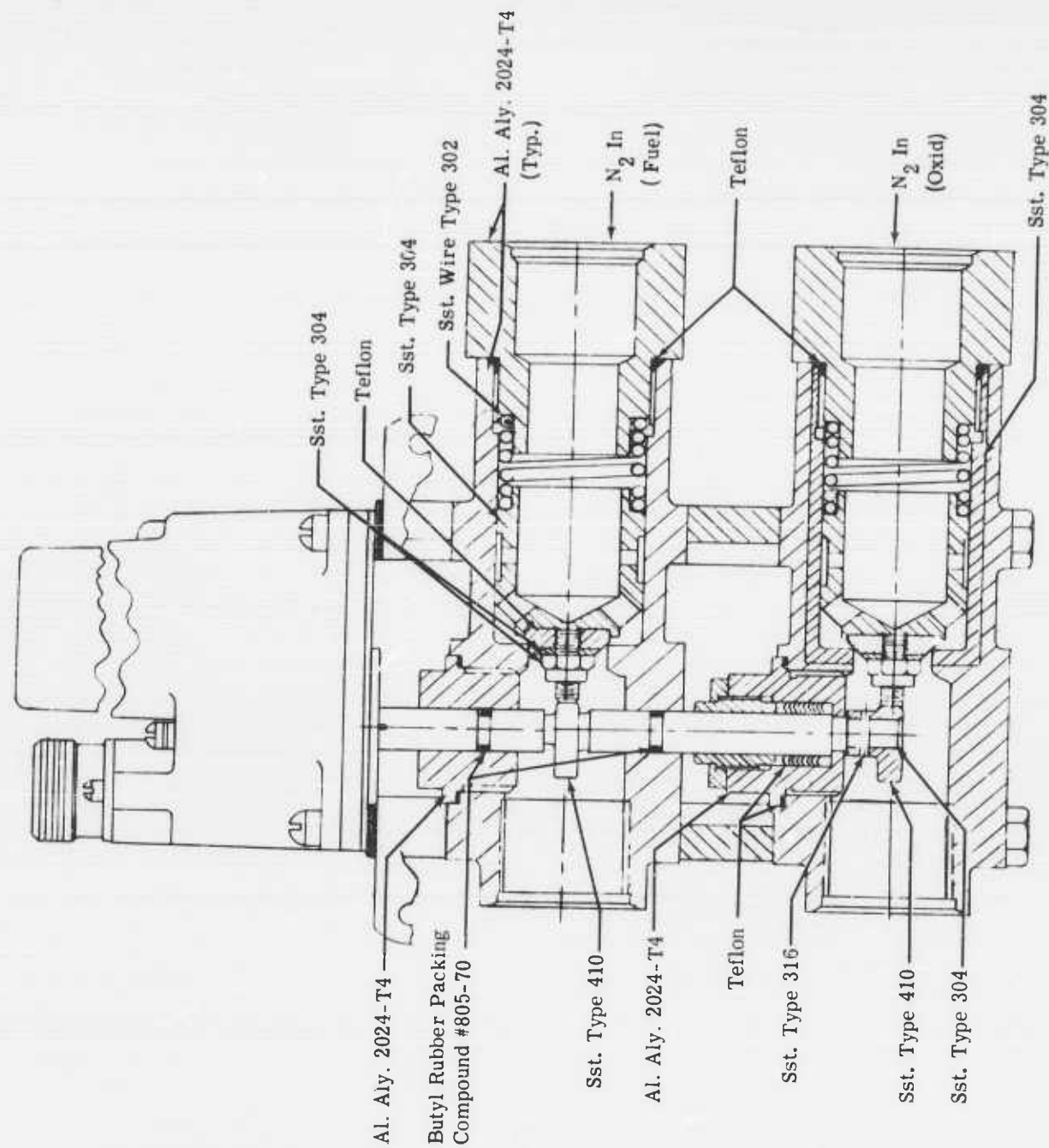
Figure 125. Cross Section - Valve Assembly - Jettison 62-472-034

Labels in figure:

Sst. Type 304
Teflon
Sst. Type 304
Sst. Wire Type 302
Al. Aly. 2024-T4 (Typ.)
N₂ In (Fuel)
Teflon
N₂ In (Oxid)
Sst. Type 304

Al. Aly. 2024-T4
Butyl Rubber Packing Compound #805-70
Sst. Type 410
Al. Aly. 2024-T4
Teflon
Sst. Type 316
Sst. Type 410
Sst. Type 304

Teflon

Kel-F, Grade 300 (Unplasticized)
5 Seals

Al. Aly. 2024-T4

Kel-F, Grade 300 (Unplasticized)

Sst Type 304
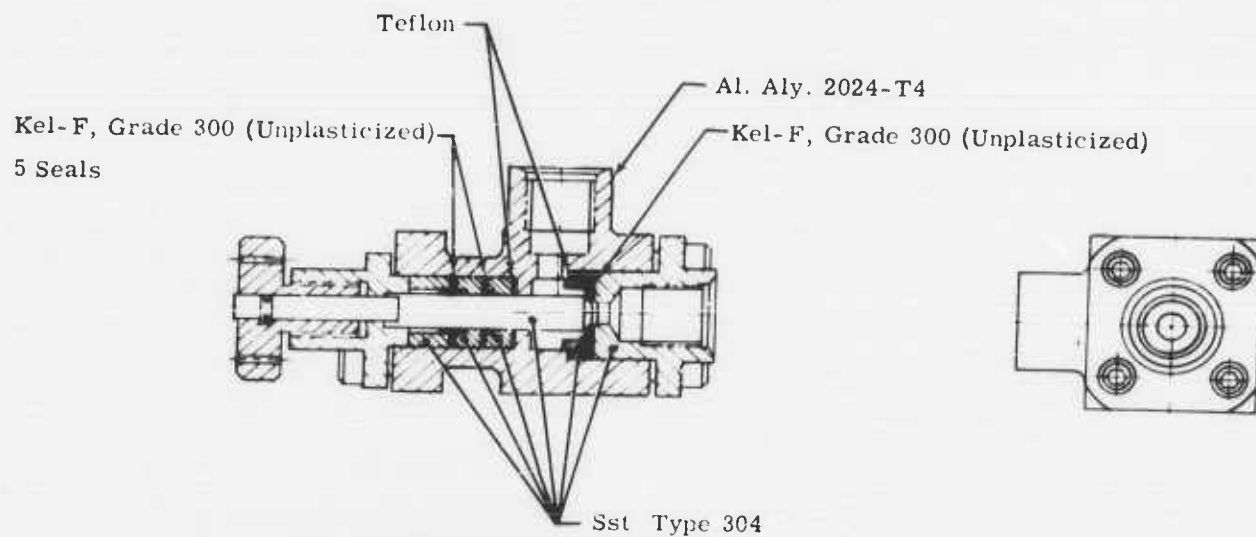
Figure 126. Cross Section - Valve Assembly - Manual Fill, Start Tank 62-472-340
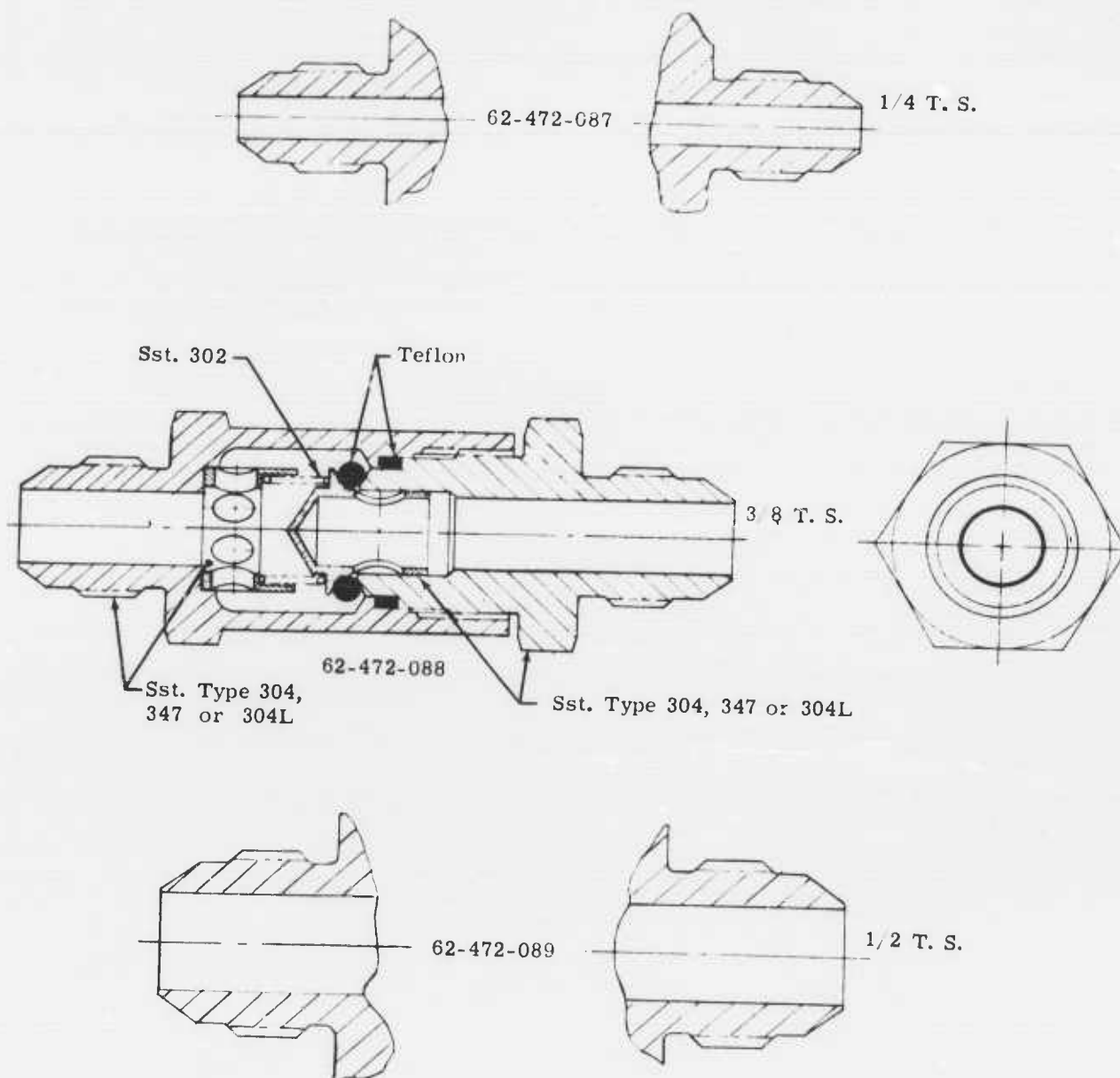
Figure 127. Cross Section - Valve Assembly - 1000 PSIG Service 62-472-087,
62-472-088, 62-472-089
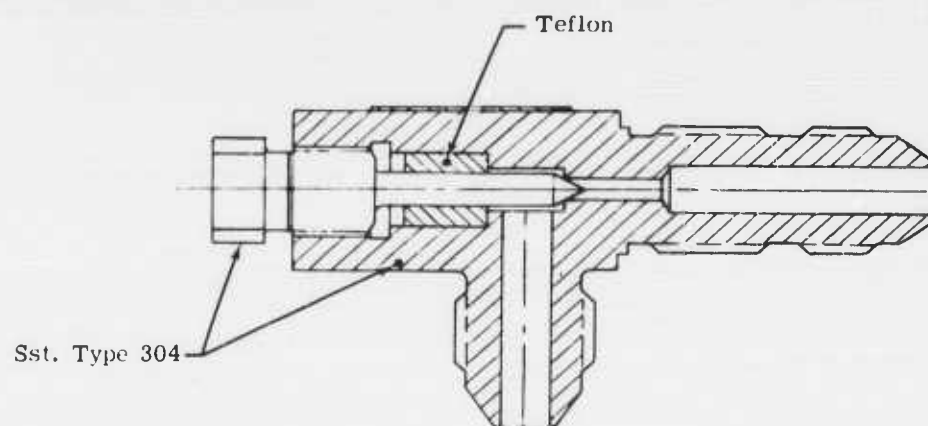
Figure 128. Cross Section - Valve Assembly - Bleed Valve 59-472-275
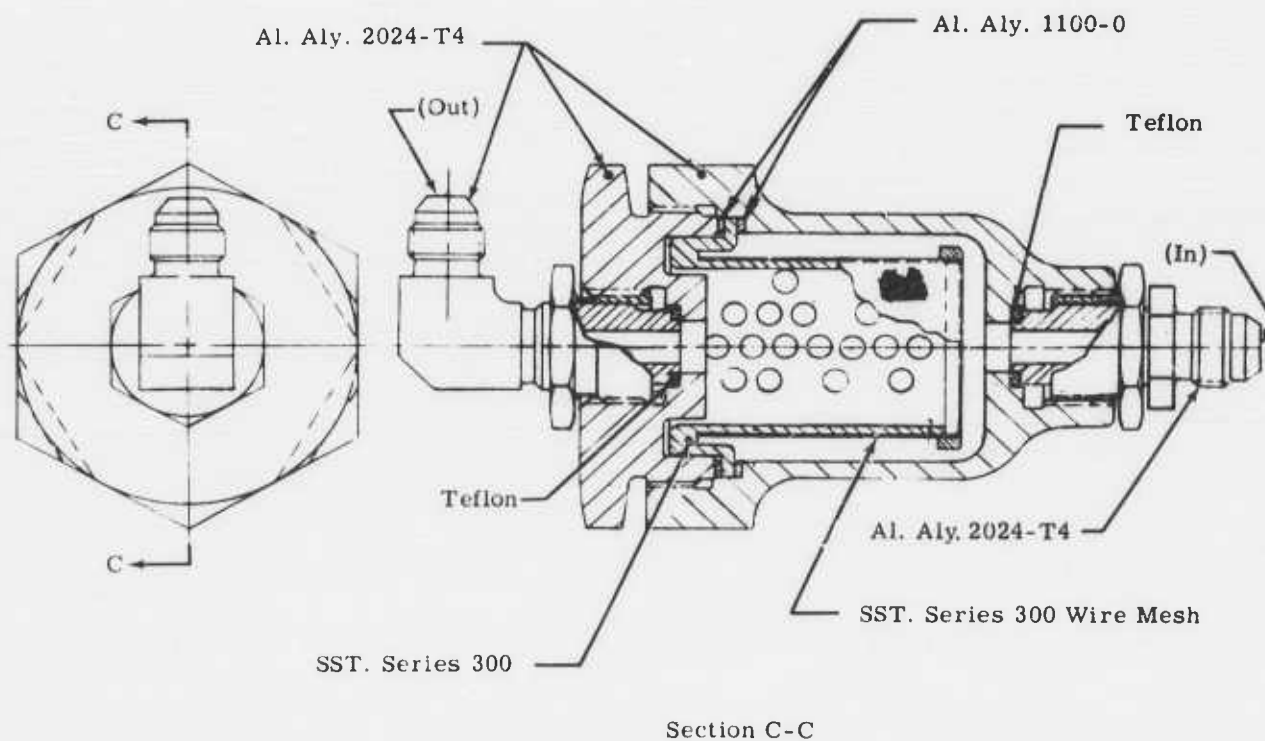
Section C-C

Figure 129. Cross Section - Filter Assembly 62-472-751-1
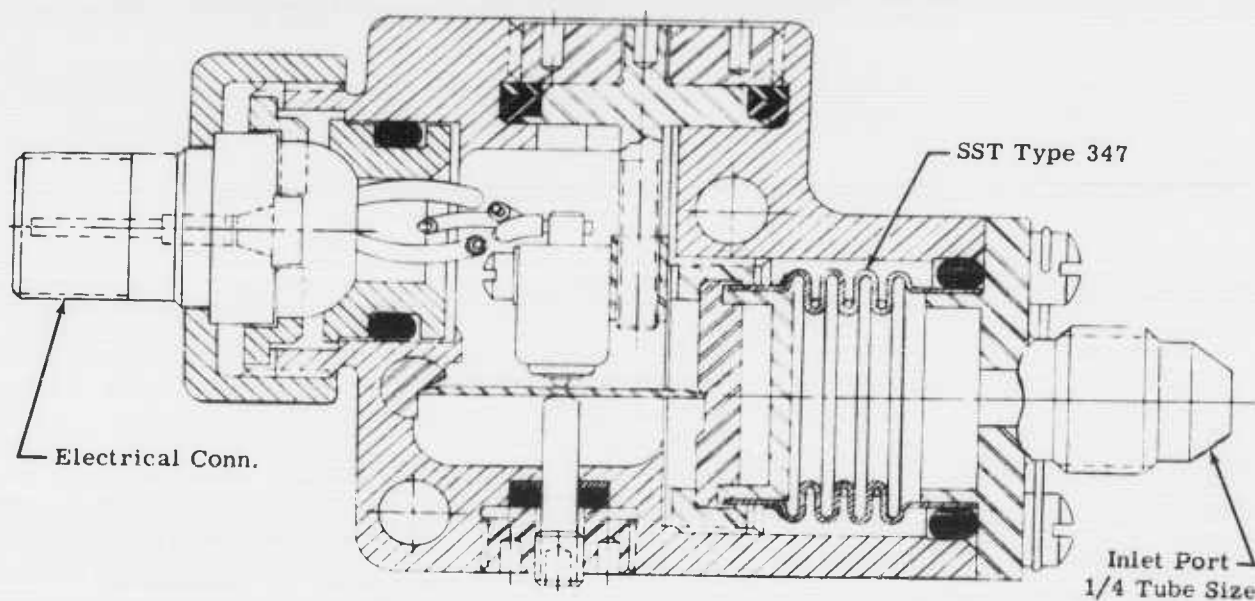
Figure 130. Cross Section - Pressure Switch Assembly 62-472-667-1, -3, -5, and -7
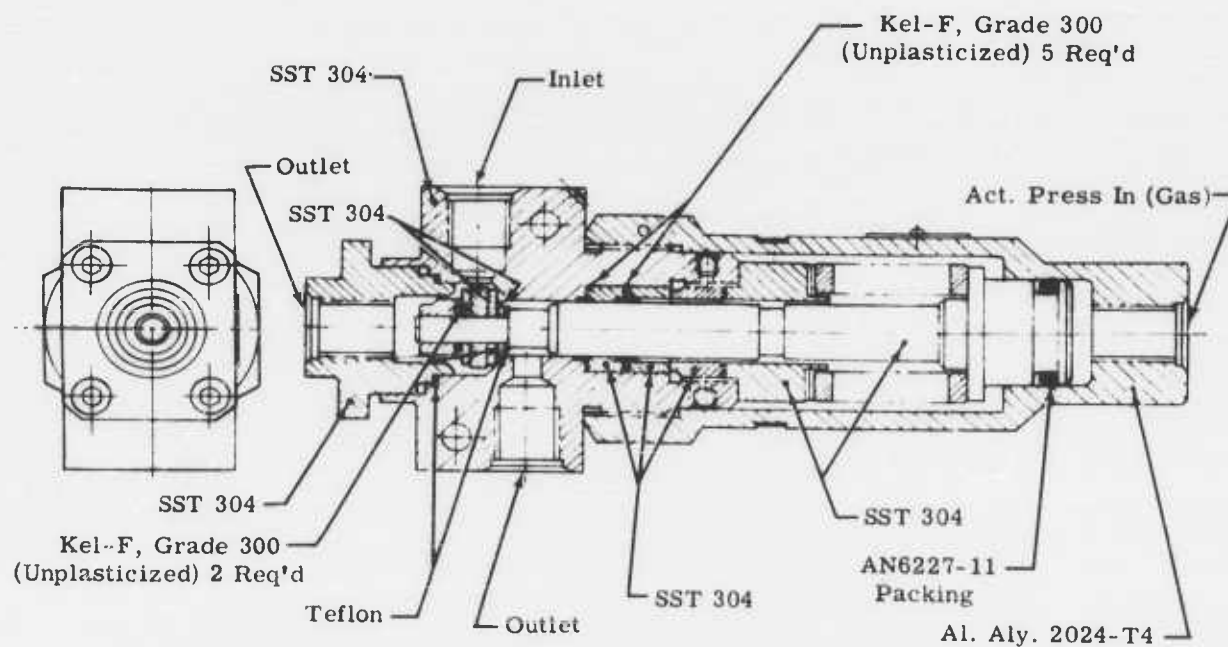
Figure 131. Cross Section - Valve Assembly - Three-Way Gas Operated 62-472-093

Electrical Connection

D

(Out)

(Alternate Out)

Butyl Rubber Packing Compound No. 805-70

Kel-F Grade 300, (Unplasticized)

(In)

D

SST. 302

Butyl Rubber Packing Compound No. 805-70

SST. Series 300

Al. Aly. 2024-T4
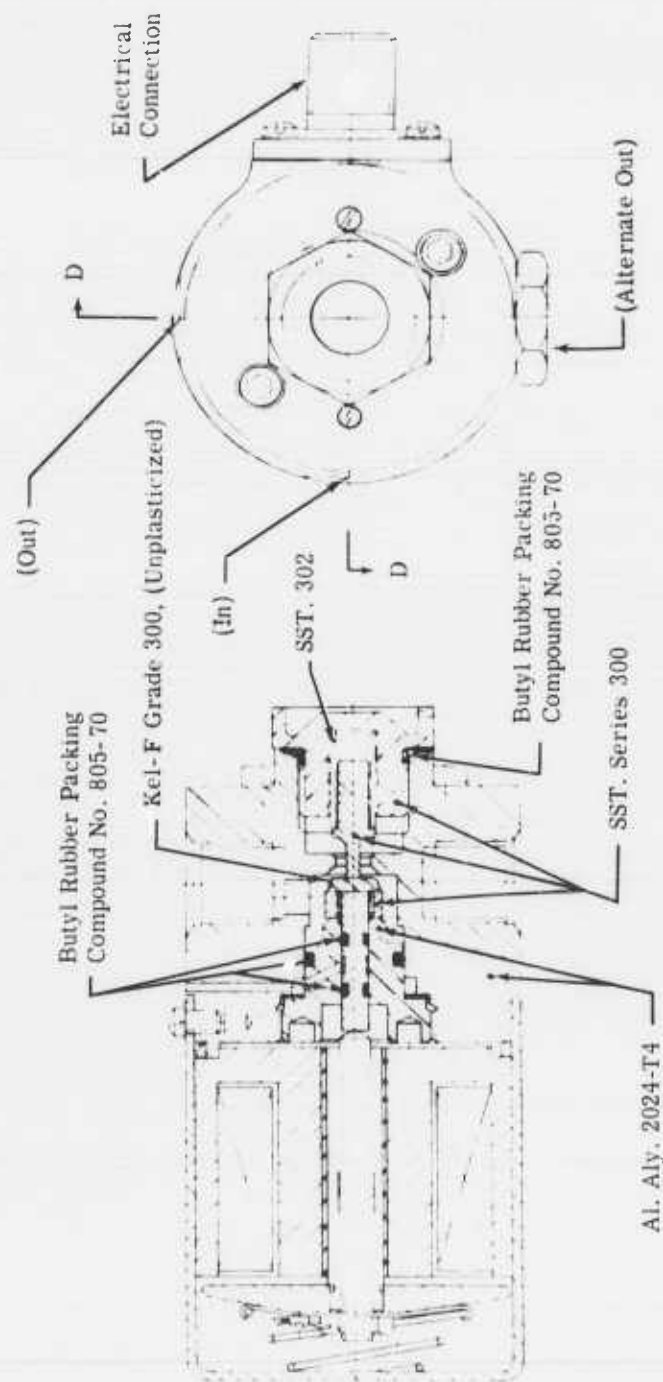
Section D-D

Figure 132. Cross Section - Valve Assembly - Solenoid Two-Way 62-472-413-1
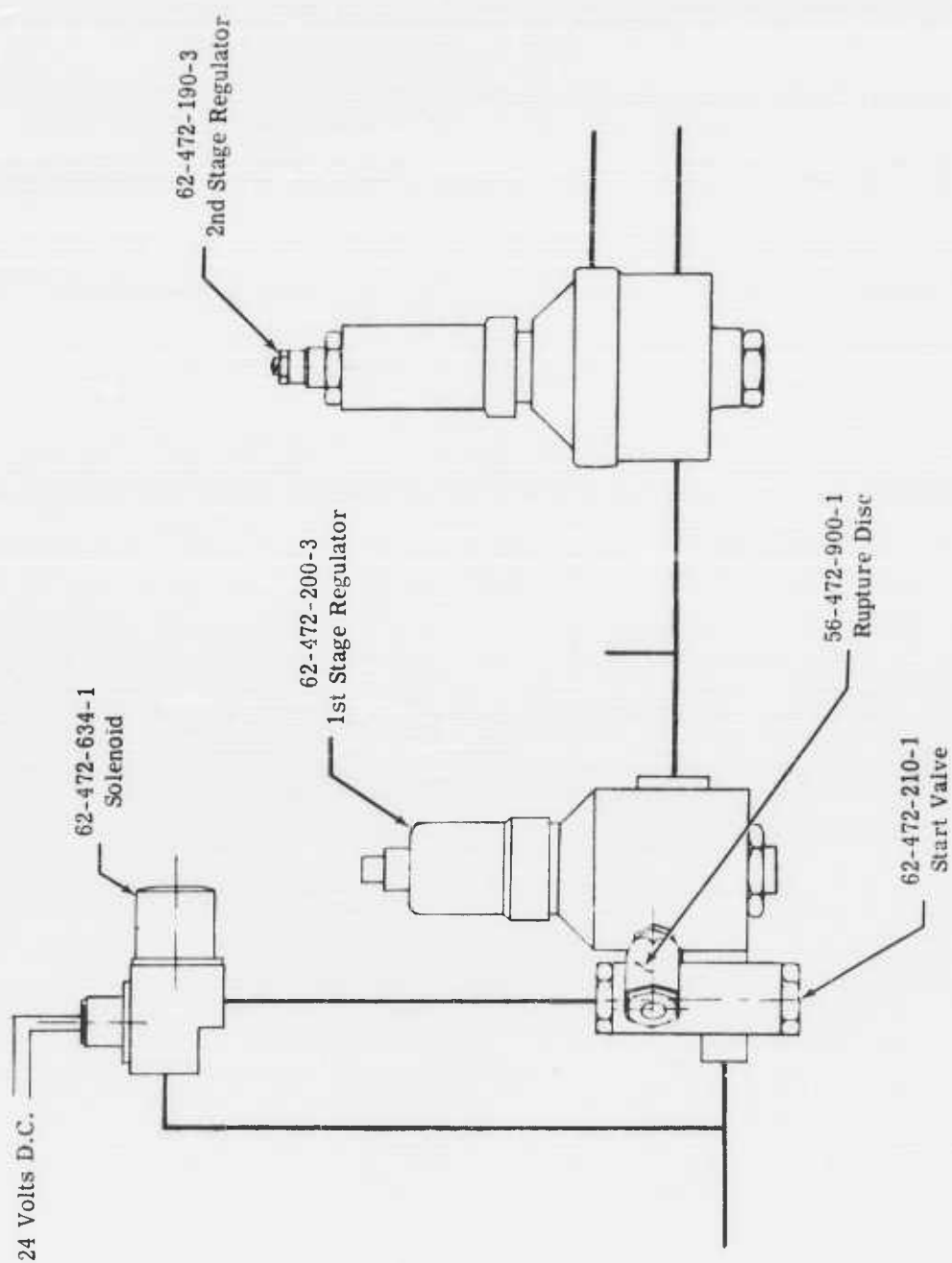
Figure 133. Regulator Pack Assembly 62-472-205 — Schematic

62-472-190-3
2nd Stage Regulator

62-472-200-3
1st Stage Regulator

56-472-900-1
Rupture Disc

62-472-634-1
Solenoid

62-472-210-1
Start Valve

24 Volts D.C.
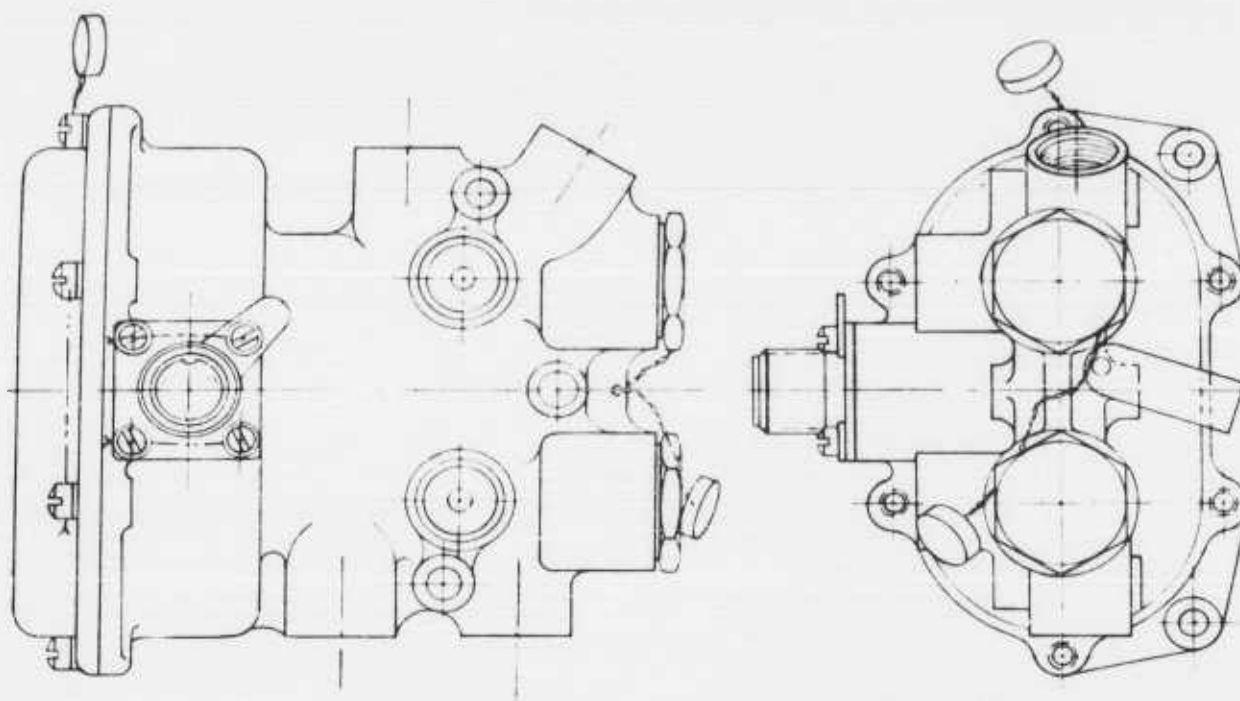
Figure 134. Cross Section - Valve Assembly - Solenoid Actuated, 5-Way 62-472-412
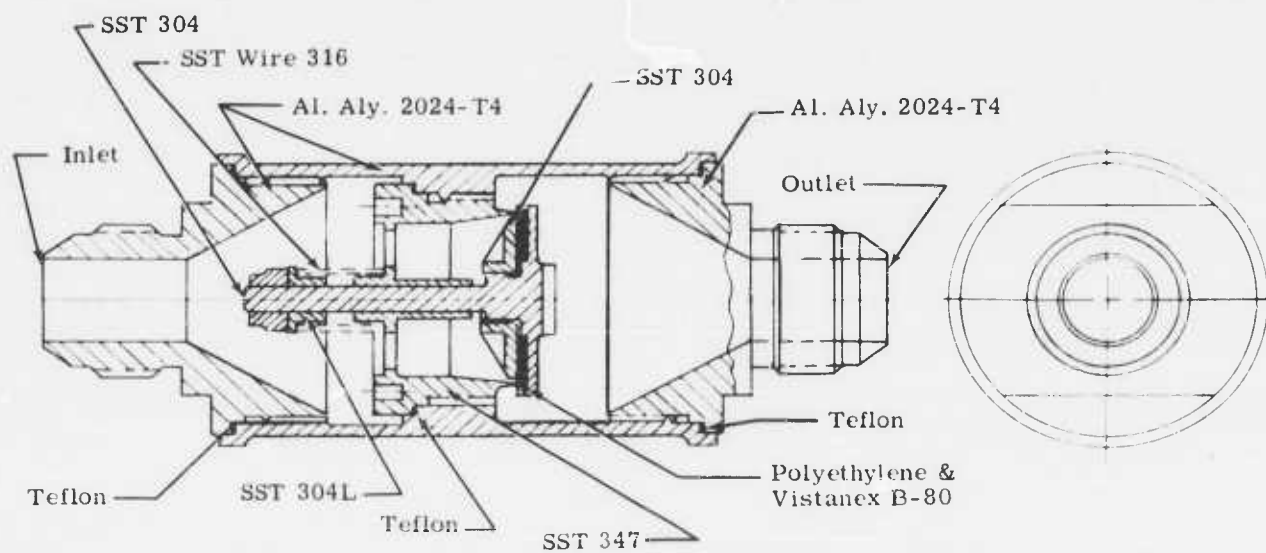
Figure 135. Check Valve Assembly 56-472-510
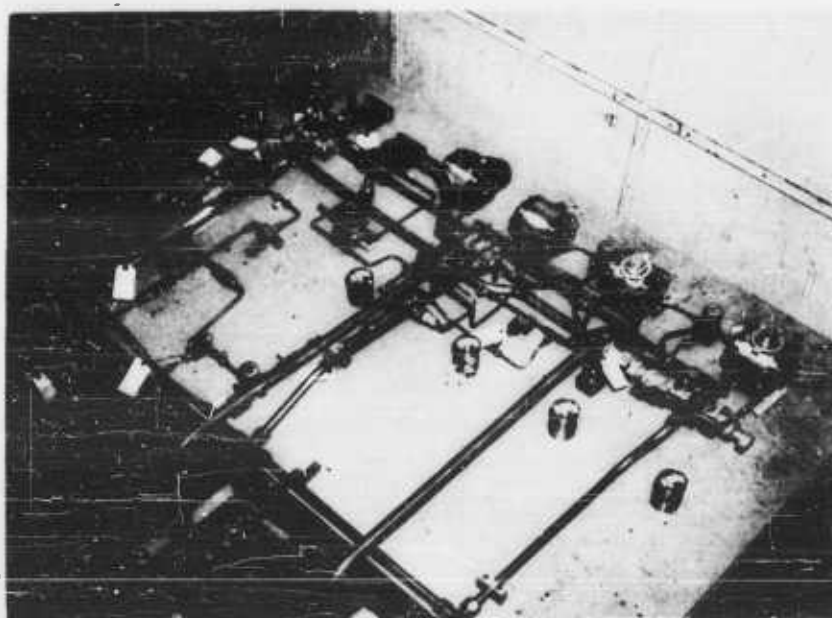
Figure 136. Mock Up of System Flow Test
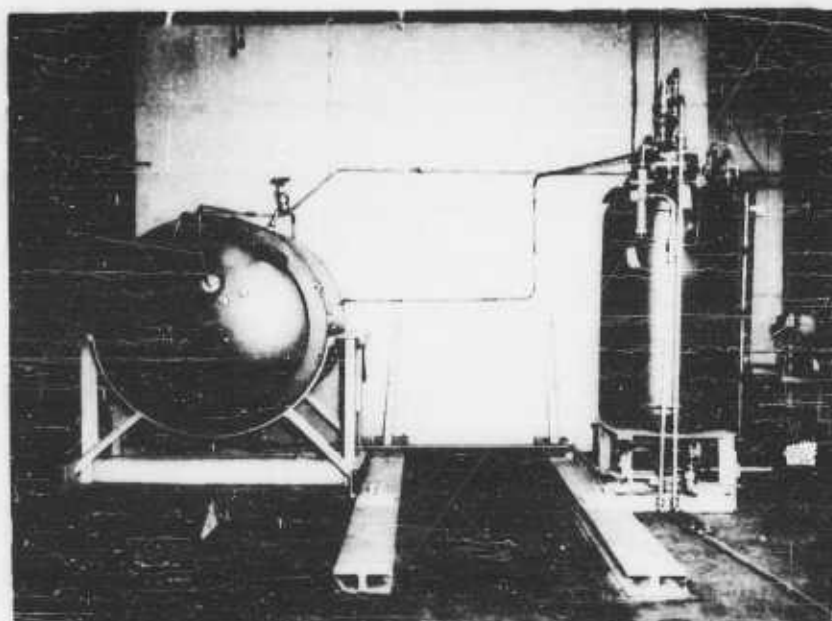
Figure 137. Fuel Side of System Flow Test Set Up
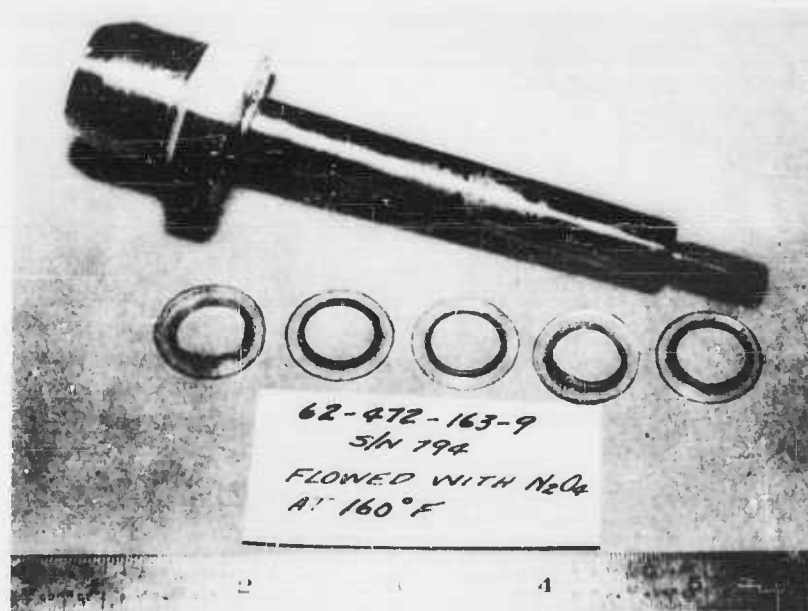
Figure 138. 62-472-163-9 S/N 794, Flowed with N_2O_4 at $160°F$ (Piston)
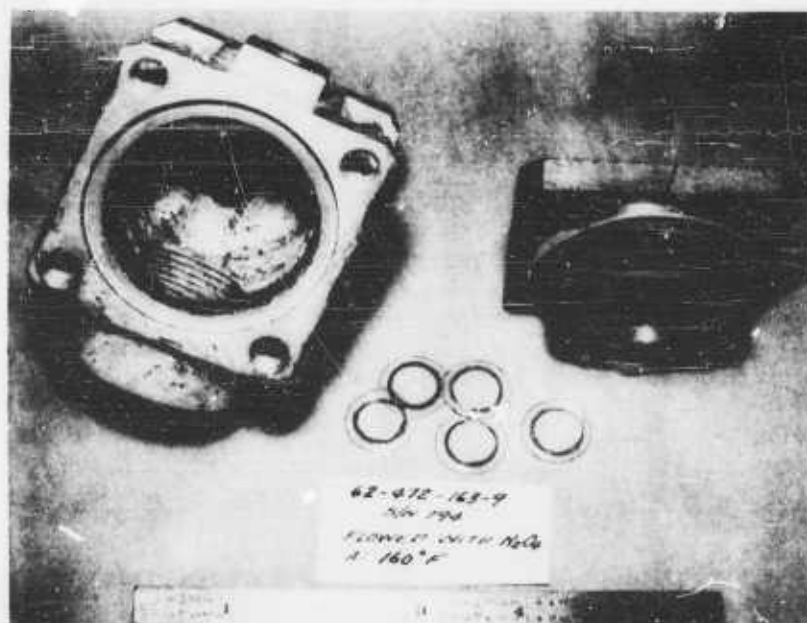
Figure 139. 62-472-163-9 S/N 794, Flowed with N_2O_4 at $160°F$ (Body)
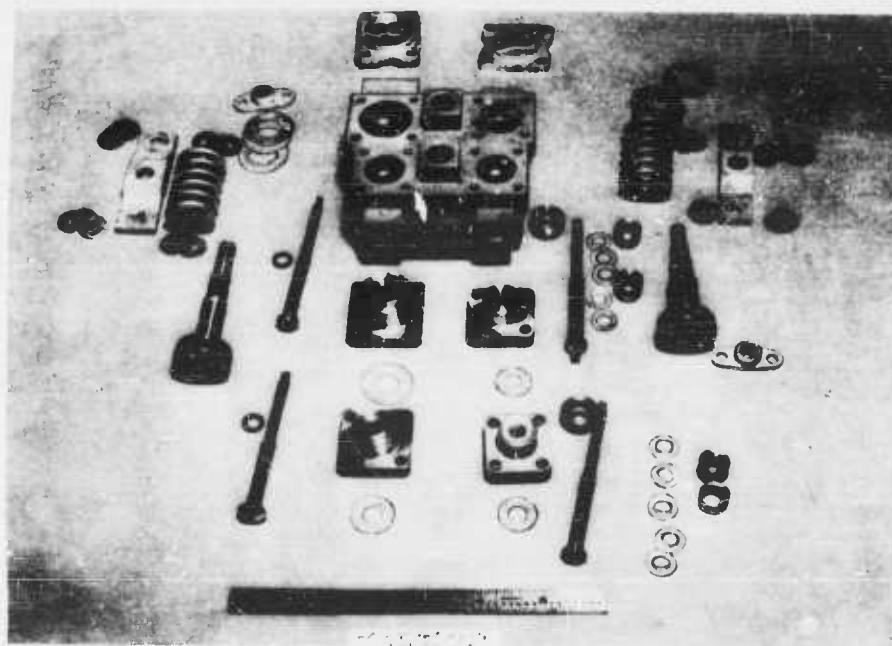
Figure 140. 62-472-367 GGPV N_2O_4 and UDMH
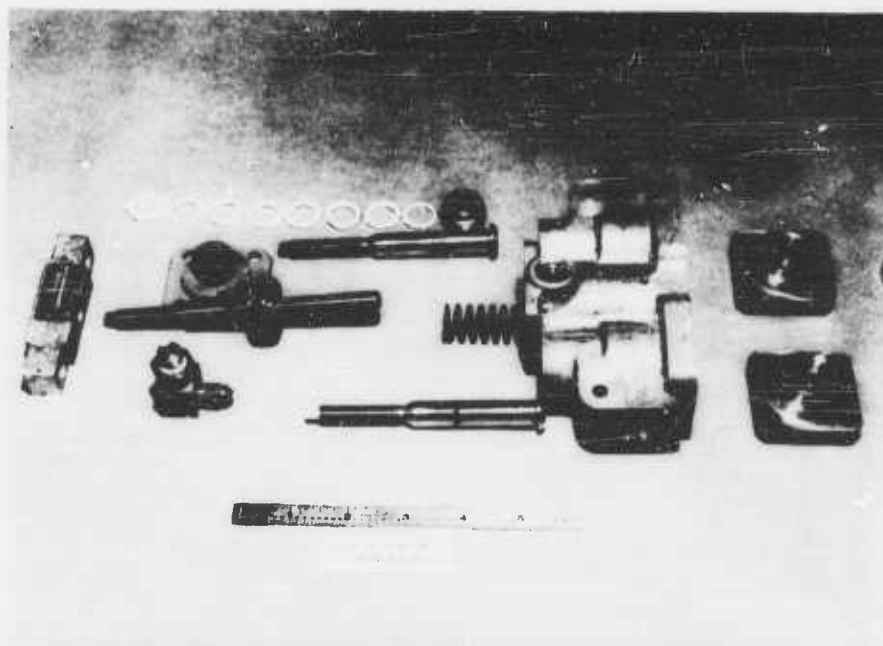
Figure 141. 62-472-213 TB PV N_2O_4 and UDMH
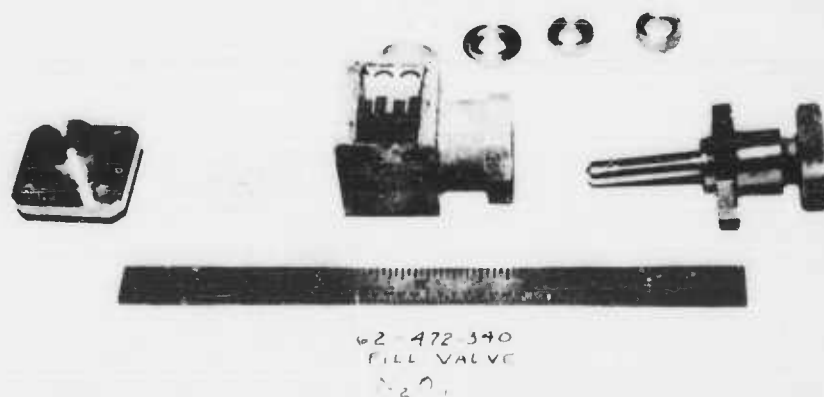
Figure 142. 62-472-340 Fill Valve N2O4
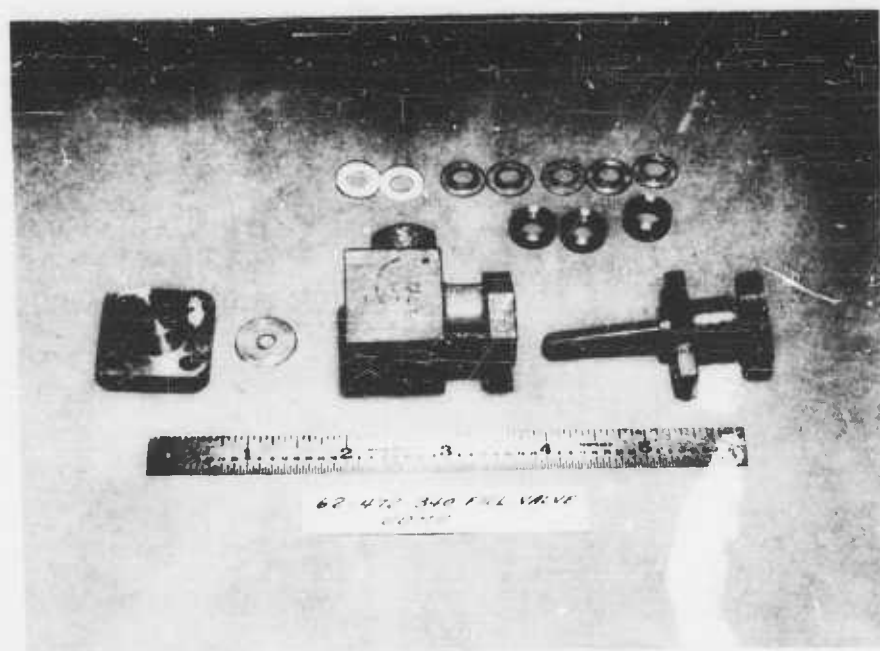
Figure 143. 62-472-340 Fill Valve UDMH
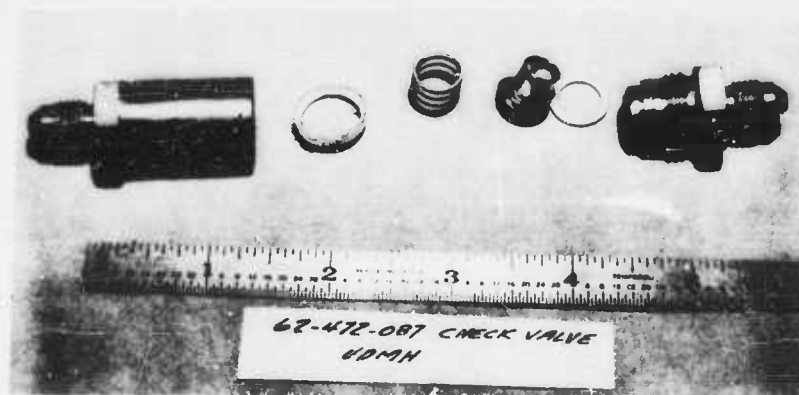
Figure 144. 62-472-087 Check Valve UDMH
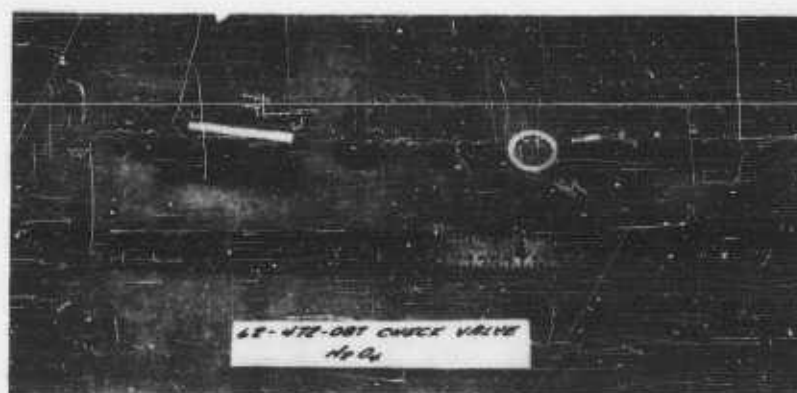
Figure 145. 62-472-087 Check Valve N2O4
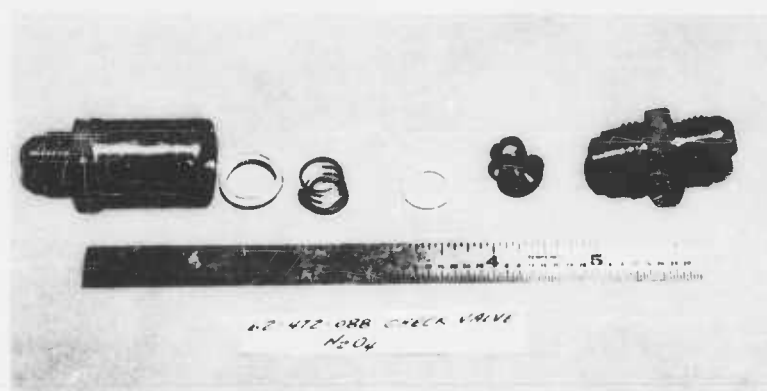
Figure 146. 62-472-088 Check Valve N2O4

Figure 147. 62-472-089 Check Valve UDMH
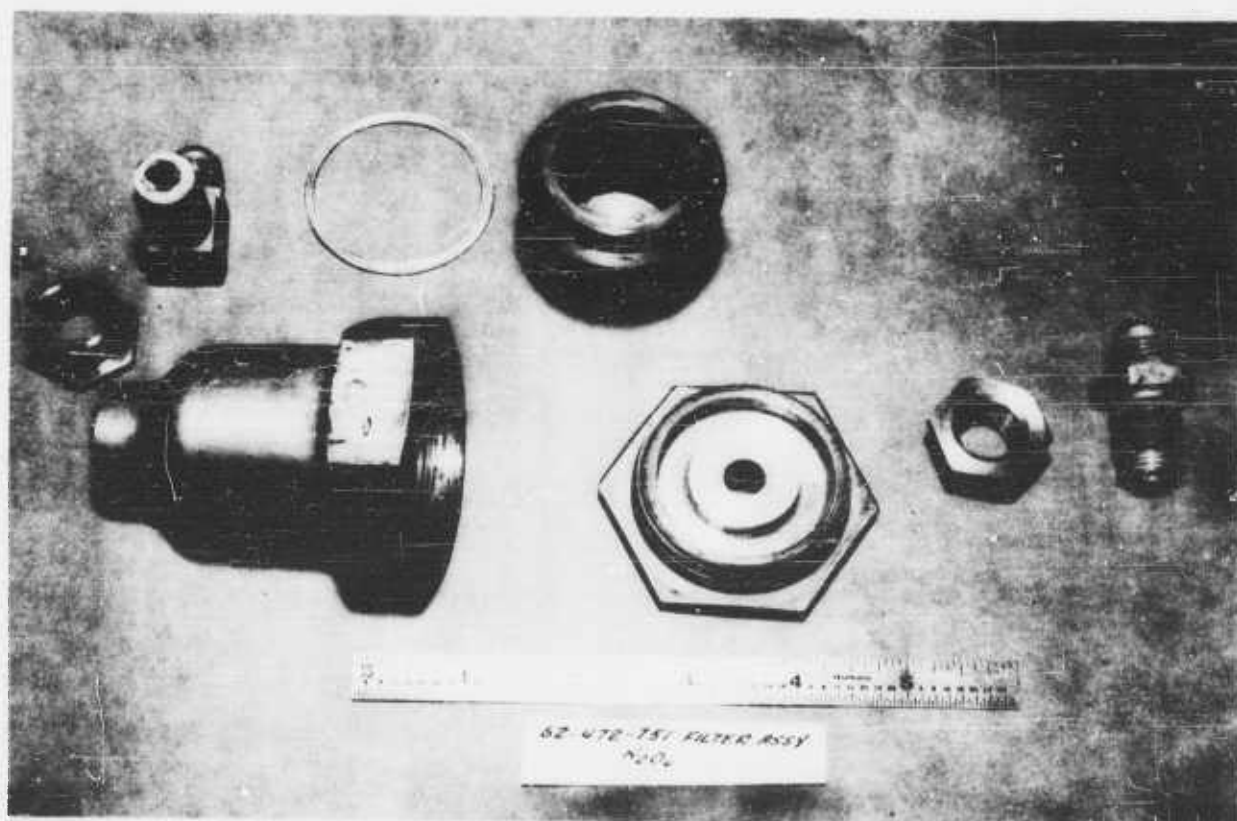
Figure 148. 62-472-751 Filter Assembly N$_2$O$_4$

Figure 149. 62-472-667-3 Pressure Switch N$_2$O$_4$

Figure 150. 62-472-667-1 Pressure Switch UDMH
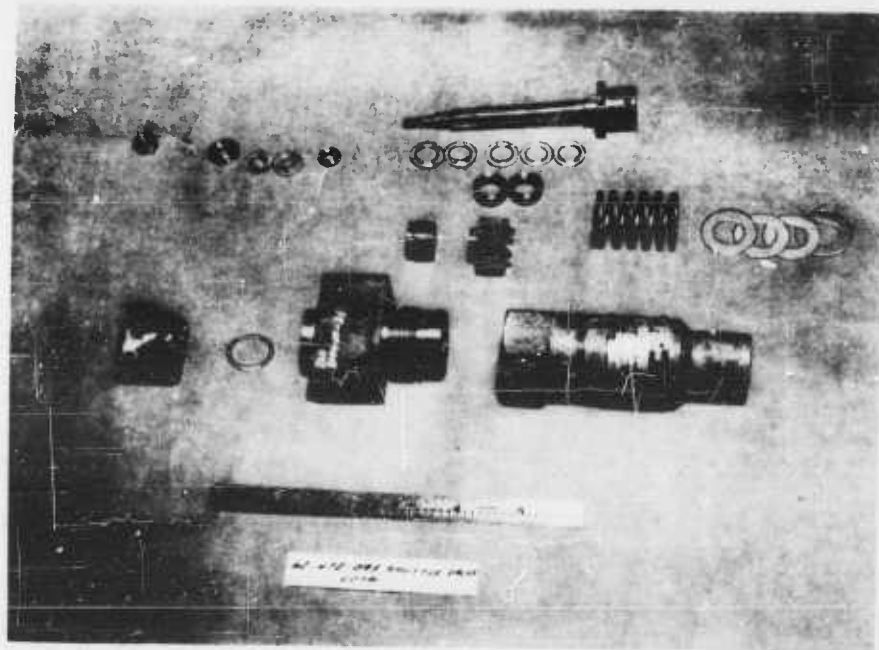
Figure 151. 62-472-093 Shuttle Valve UDMH
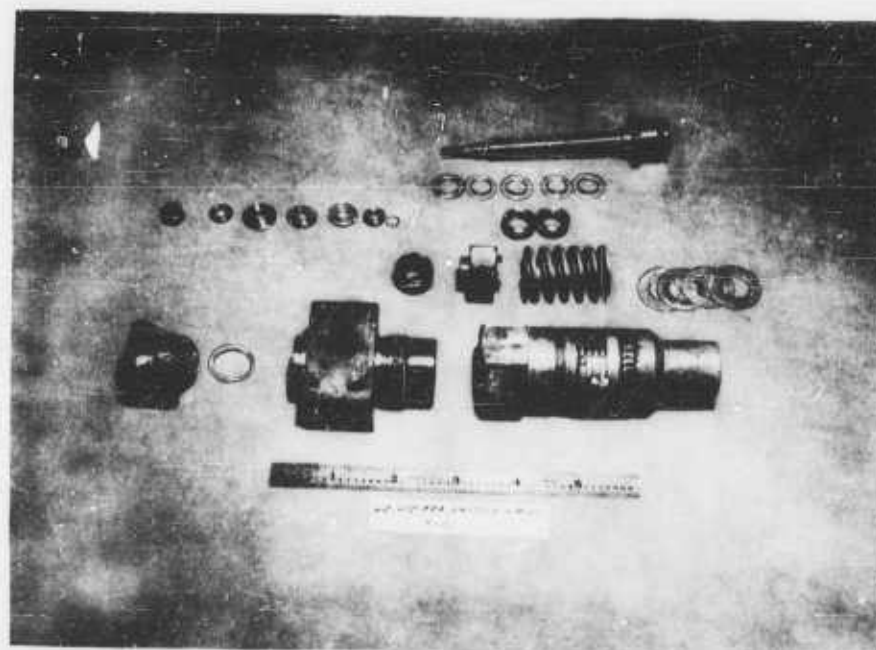
Figure 152. 62-472-093 Shuttle Valve N$_2$O$_4$

Figure 153. 62-472-413 Marotta 2-Way UDMH
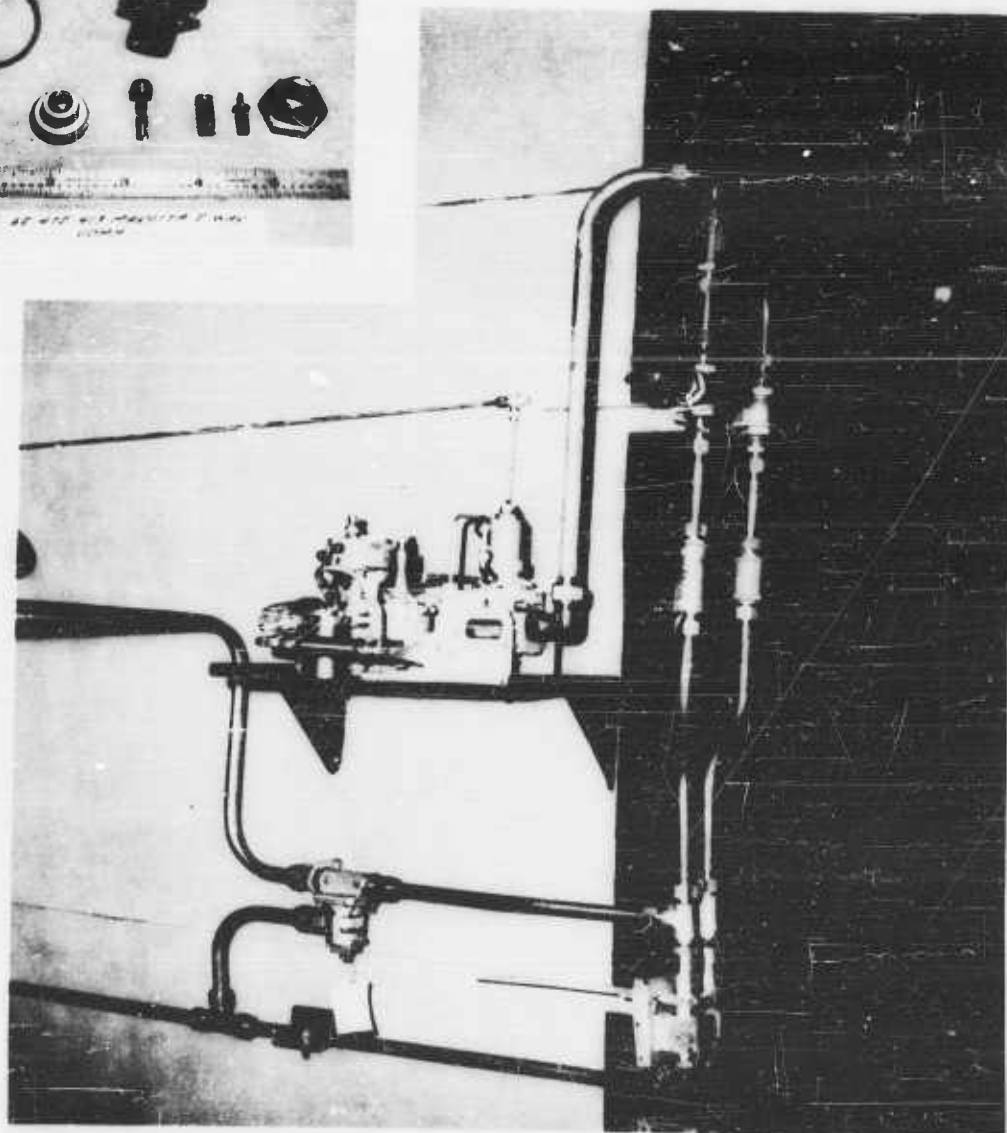
Figure 154. Regulator Pack
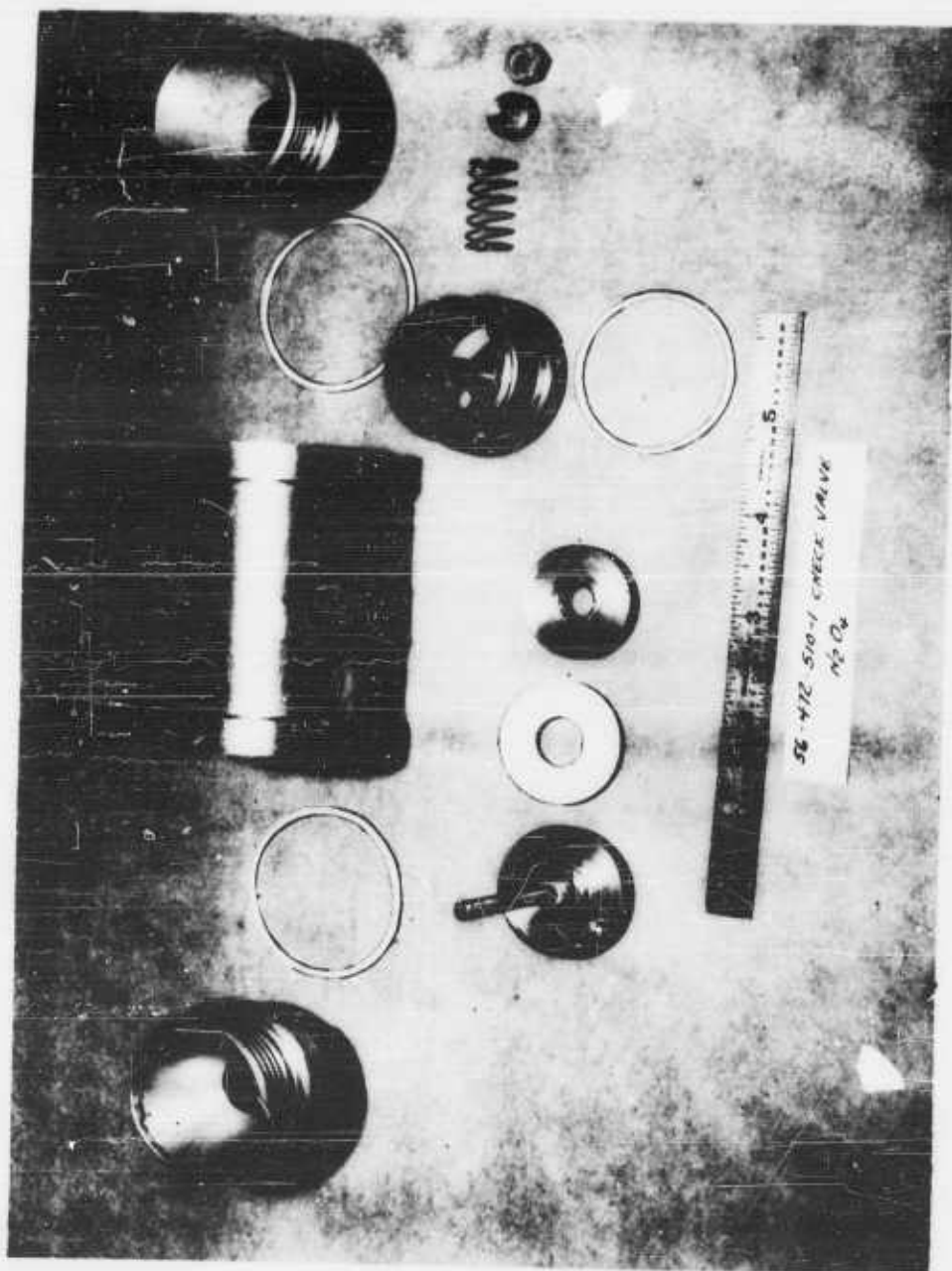
Figure 155. 56-472-510-1 Check Valve N2O4
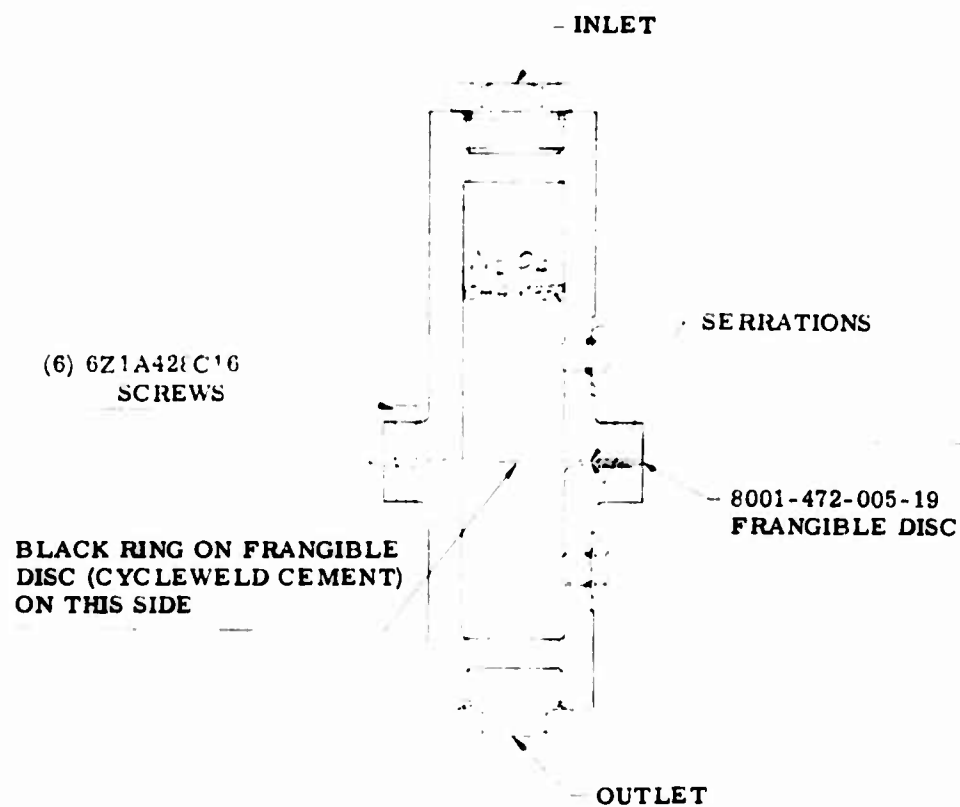
Figure 156. Storage Fixture - Aluminum Frangible Disc Exposed to N_2O_4
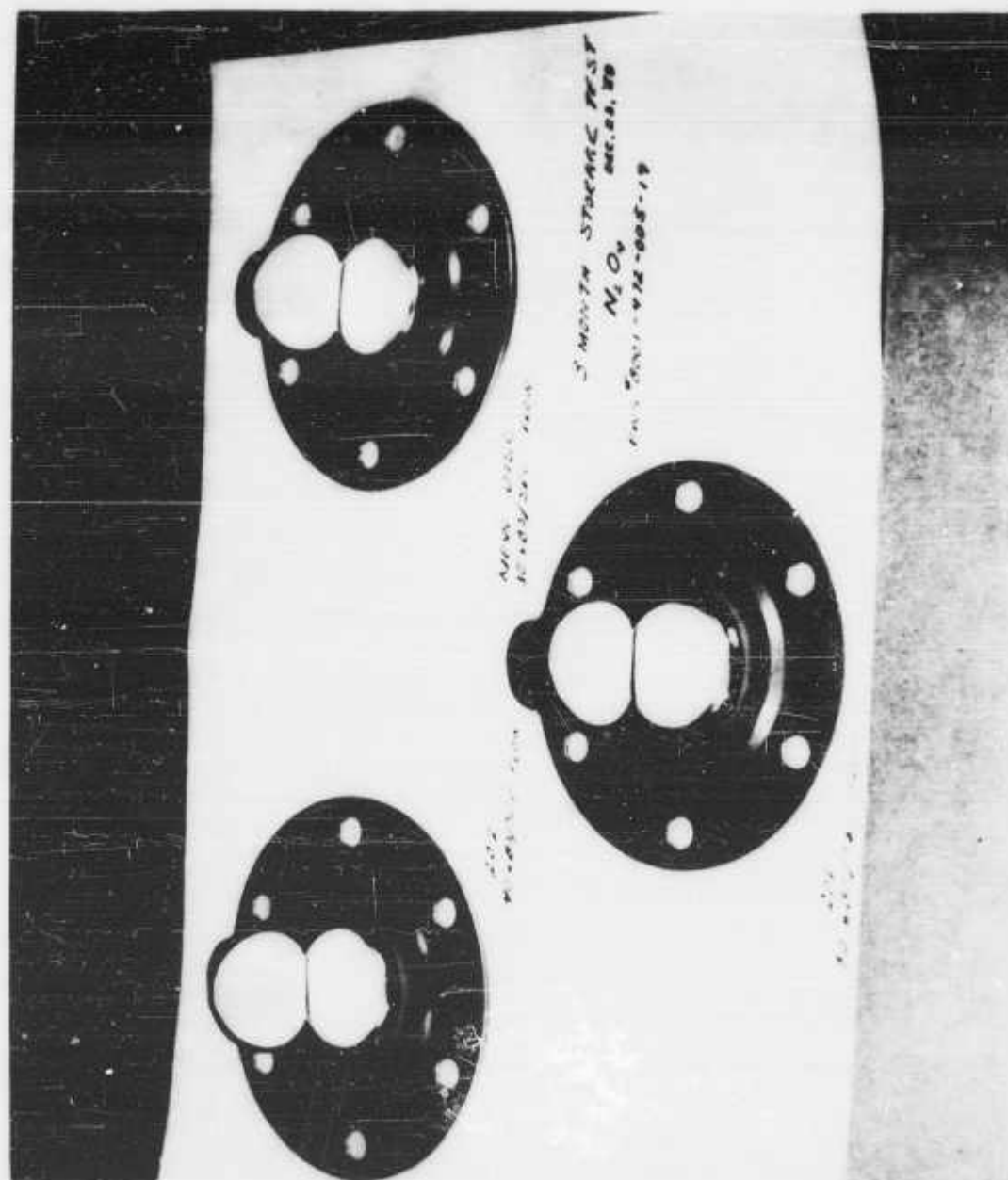
Figure 157. Three-Month Storage Test N_2O_4
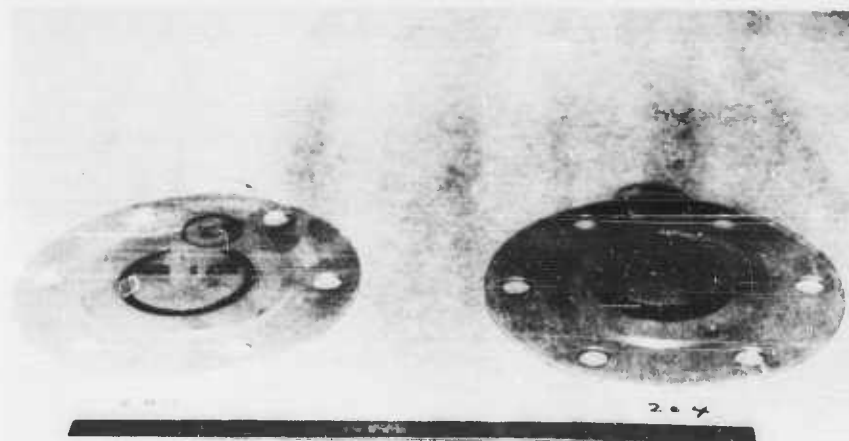
Figure 158. Discs After Six Months Exposure to N_2O_4
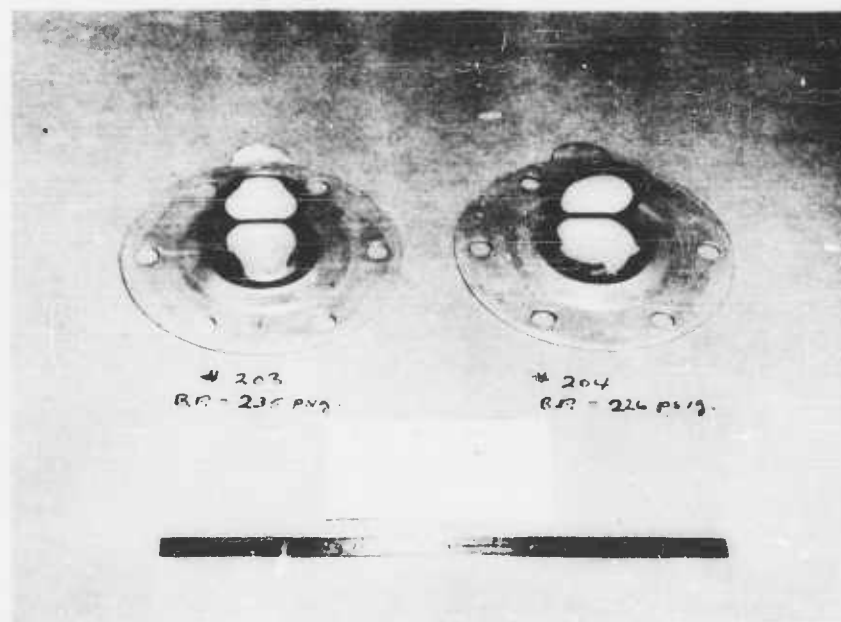
Figure 159. Burst Characteristics of Discs After Six Months Exposure to N_2O_4
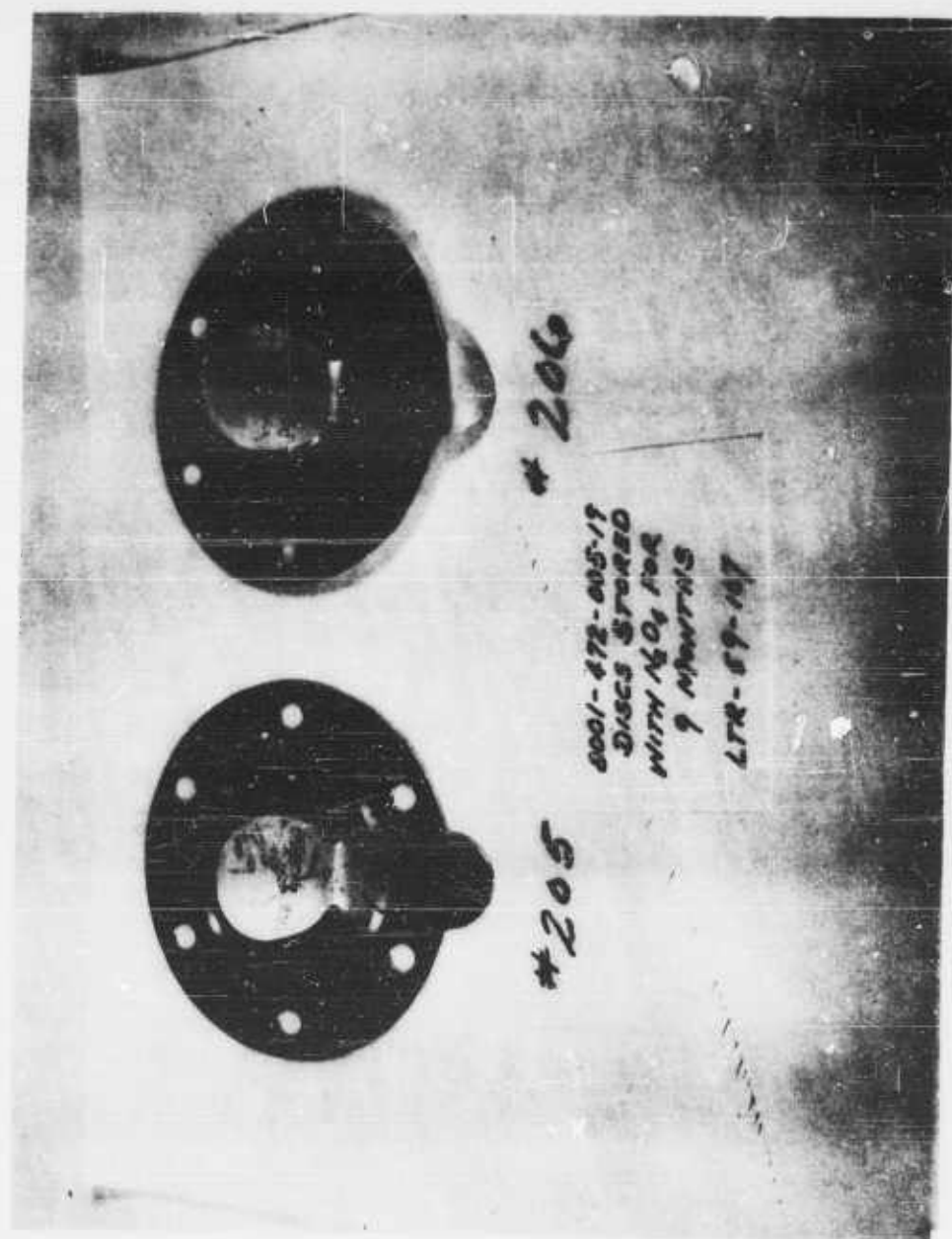
Figure 160. 8001-472-005-19 Discs Stored with N$_2$O$_4$ for Nine Months LTR-59-167

BLACK RING ON FRANGIBLE DISC
(CYCLEWELD CEMENT)
— ON THIS SIDE —

— OUTLET

— INLET

UDMH
CHAMBER

607-015-224-9
FRANGIBLE DISC
NO. 2

— 607-015-224-9
FRANGIBLE DISC
NO. 1
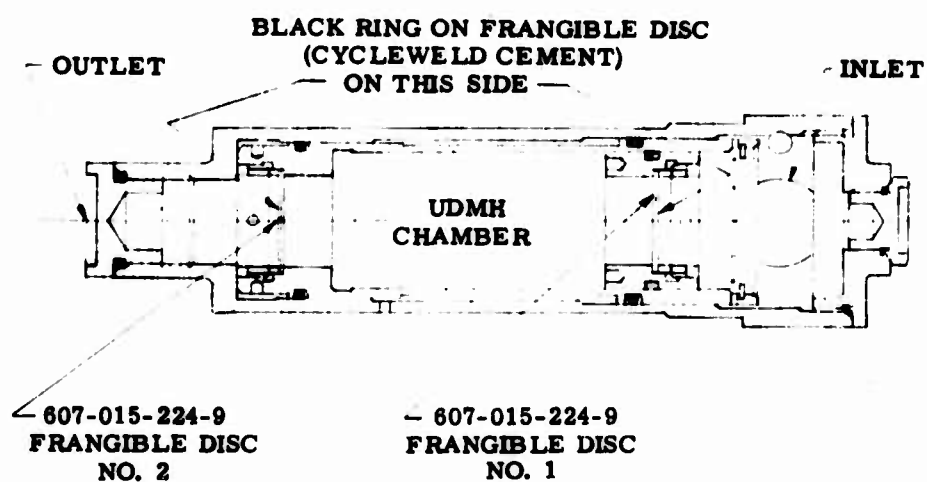
Figure 161. Storage Fixture — Aluminum Frangible Disc Exposed to UDMH

#1 NEW DISCS #2
3 LBS SEC FLOW

#1 FIXTURE 201 #2
4 LBS SEC FLOW

#1 FIXTURE 202 #2
3 LBS SEC FLOW

Figure 162. Burst Characteristics of Reference Discs Comp with Discs Exposed to UDMH
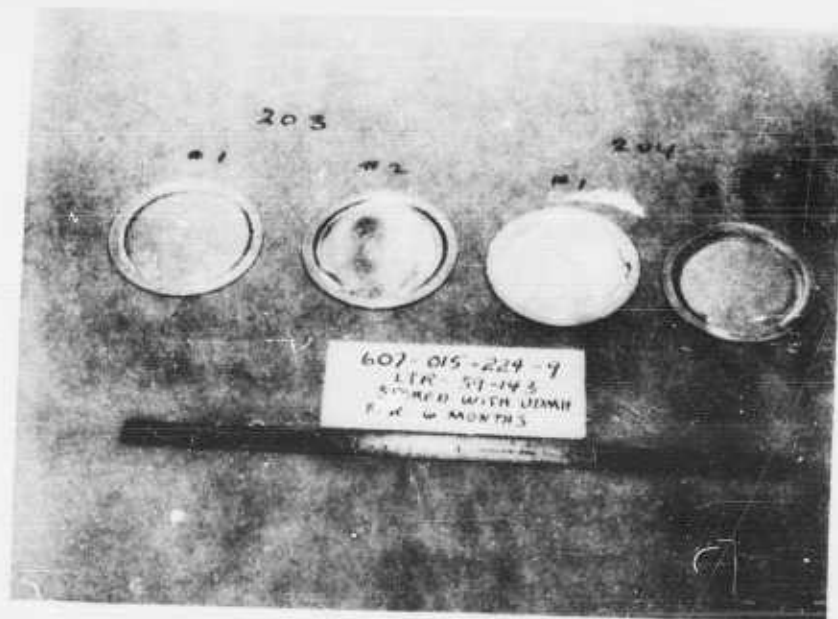
Figure 163. Discs After Six Months Exposure to UDMH
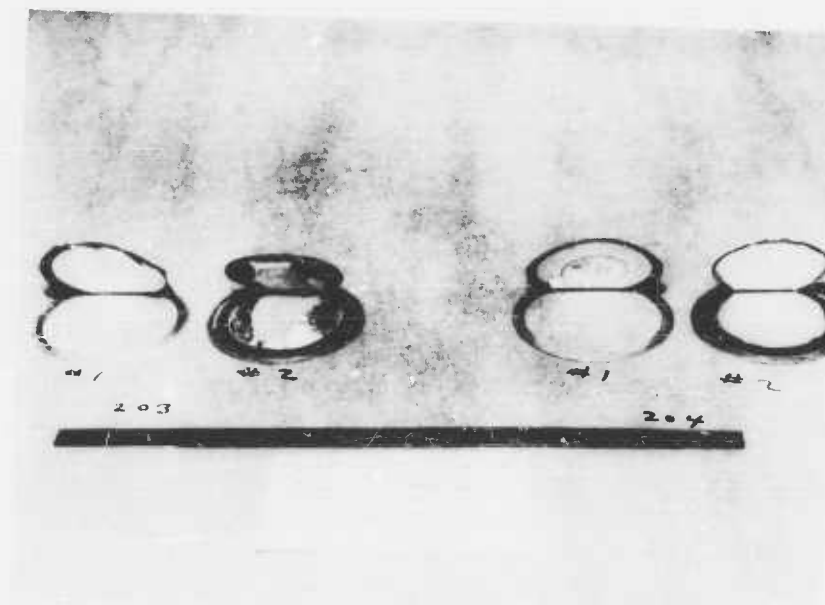
Figure 164. Burst Characteristics of Discs After Six Months Exposure to UDMH
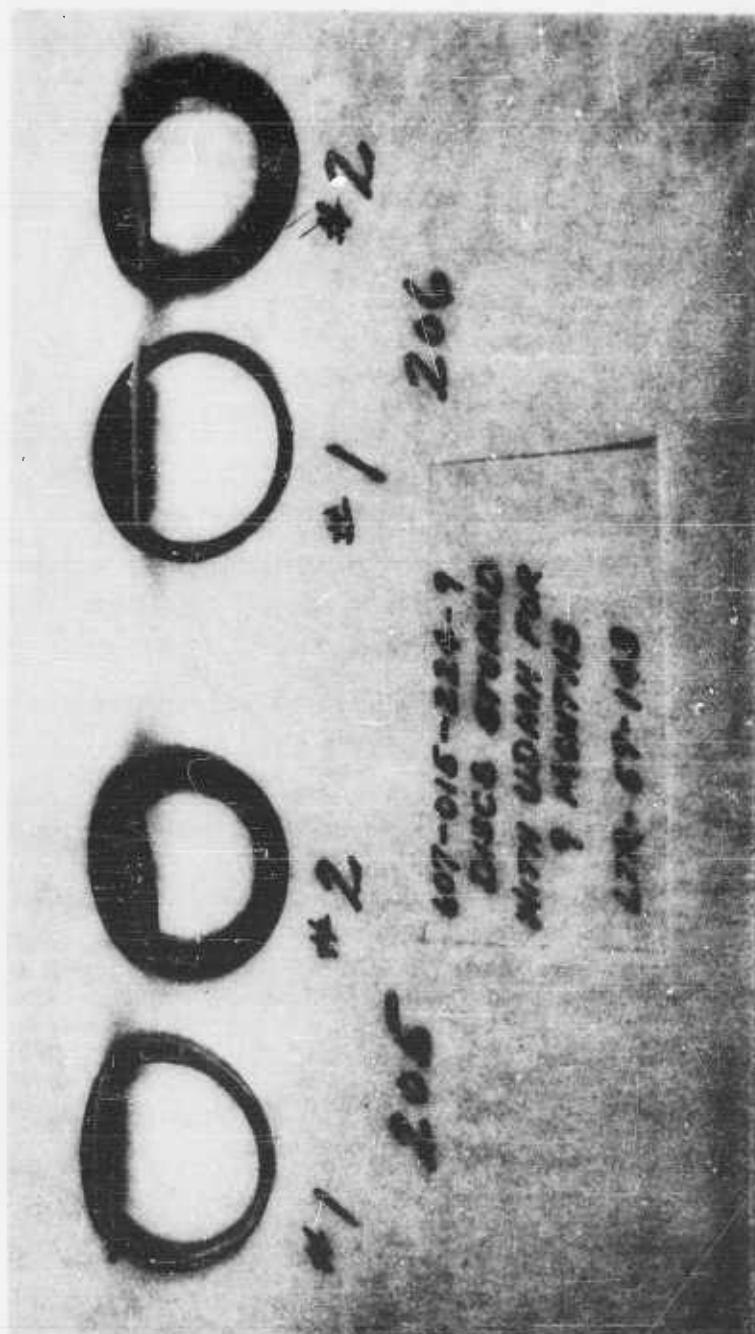
Figure 165. 607-015-224-9 Discs Stored with UDMH for Nine Months LTR-59-143

TABLE 1
PROPELLANT PHYSICAL PROPERTIES

	UDMH	Anh. N_2H_4	N_2O_4
Empirical Formula	$C_2H_8N_2$ (2)	N_2H_4 (4)	$N_2O_4 \rightleftharpoons 2NO_2$ (9)
Structural Formula	$\begin{array}{c} H_3C \quad\quad H \\ \diagdown\;\;\diagup \\ N\text{-}N \\ \diagup\;\;\diagdown \\ H_3C \quad\quad H \end{array}$	$\begin{array}{c} H \\ \mid \\ H\text{-}N\text{-}N\text{-}H \quad (5) \\ \mid \\ H \end{array}$	$\begin{array}{c} O \quad\quad O \\ \diagdown\;\;\diagup \\ N\text{-}N \quad (10) \\ \diagup\;\;\diagdown \\ O \quad\quad O \end{array}$
Molecular Weight	60.09 (3)	32.05 (4)	92.016 (9)
Physical State	Colorless hygro-scopic liquid (2) and (3)	Colorless hygro-scopic liquid (6)	Heavy brown liquid (9)
Melting Point, °C °F	-57.21 (3) -70.97	2 (6) 35.6	-11.2 (9) 11.84
Boiling Point, °C °F	63.1 (3) 145.58	113.5 (6) 236.3	21.15 (9) 70.07
Heat of Combustion, kcal/mole BTU/lb	472.6 (3) 14200	148.6 at 25°C (6) 8346 at 77°F	— —
Heat of Formation, kcal/mole at 25°C BTU/lb at 77°F	12.735 (12) 381	12.0 (6) 676.8	2.309 (9) 45.21
Vapor Pressure at 68°F	2.4 psia (2)	0.2040 psia (6)	13.93 psia (9)
Viscosity at 68°F, Centipoise lb/ft-sec	0.552 (2) 0.000374	0.9736 (7) 0.00654	0.416 (11) 0.000280
Density, lb/cu. ft at 68°F	49.57 (2)	62.96 (7)	90.21 (9)
Heat Capacity, BTU/lb-°F at 68°F	0.651 (2)	0.736 (4)	0.367 (9)[a]
Heat of Vaporization, BTU/lb	251 (12) at 77°F	601.9 (7) at 77°F	178 (9) at 70°F and 14.7 psia
Heat of Fusion, BTU/lb	72 (12) at -71°F	0.3751 (7) at 34.7 F	68.4 (9)

TABLE 1 (CONT)

	UDMH	Anh. N_2H_4	N_2O_4
Critical Temperature, C	249 (3)	380 (6)	158.2 (9)
F	480	716	316.8
Critical Pressure, atm	60 (3)	145 (6)	99.96 (9)
psia	880 (8)	2135	1469
Flash Point			
Open Cup, F	5 (3)	125.6 (6)	—
C	-15	52	
Closed Cut, F	34 (8) (3)	104 (13)	—
C	1.1	40	
Fire Point			
Open Cup, F	5 (14)	125.6 (5)	—
C	-15	52	
Closed Cup, F	34 (14)	104 (13)	—
C	1.1	40	
Spontaneous Ignition F	482 (15)[b]	313 (16)[c]	—
Spontaneous De- composition, F	>1112 (15)[d]	931 (16)[e]	—

a - Extrapolation

b - In air at 14.7 psia in Pyrex glass

c - In stainless steel and in air; this value is >780 F in nitrogen

d - In nitrogen at 14.7 psia

e - In nitrogen at 200 psig

TABLE 2

DENSITY OF LIQUID N_2O_4
(Under its own Vapor Pressure)

Temperature		Density		
°C	°F	g/cc	lb/cu ft	lb/gal
0	32	1.4905	93.05	12.44
10	50	1.4700	91.77	12.27
20	68	1.4470	90.34	12.08
25	77	1.4310	89.34	11.94

Reference 9

TABLE 3

VAPOR PRESSURE OF N_2O_4

Temperature °F	Pressure Lb/Sq Inch Absolute	Temperature °F	Pressure Lb/Sq Inch Absolute
70	14.78	200	235.01
80	18.98	210	281.56
90	24.21	220	332.8
100	30.69	230	393.2
110	38.62	240	463.3
120	48.24	250	543.9
130	59.98	260	636.3
140	74.12	270	732.6
150	91.06	280	864.1
160	111.24	290	1000.5
170	135.14	300	1160.1
180	163.29	310	1336.5[a]
190	196.35	316.8[b]	1469.0[a]

a - Value extrapolated.
b - Critical pressure estimated from measured critical temperature.

Reference 9

TABLE 4

VISCOSITY OF N_2O_4 IN THE LIQUID PHASE

Pressure Lb/Sq Inch Abs	Temperature °F								
	40	70	100	130	160	190	220	250	280
	Bubble Point Pressure, Pounds Per Square Inch Absolute								
		14.8	30.7	60.0	111.2	196.4	332.8	543.9	864.1
	Viscosity, Micropoises								
Bubble Point	4990	4132	3420	2784	2235	1752	1325	924	570
200	5021	4155	3441	2800	2250	1753			
400	5055	4180	3470	2820	2281	1804	1350		
600	5090	4208	3495	2840	2310	1850	1420	948	
800	5121	4232	3520	2861	2334	1896	1482	1028	
1000	5150	4260	3544	2880	2355	1939	1539	1100	630
1250	5190	4297	3566	2906	2380	1975	1599	1179	713
1500	5230	4330	3587	2929	2400	2010	1646	1252	798
1750	5270	4366	3608	2949	2420	2040	1686	1319	881
2000	5310	4400	3628	2965	2440	2063	1720	1370	940
2250	5345	4433	3649	2990	2459	2080	1742	1400	990
2500	5382	4470	3670	3010	2480	2098	1764	1430	1045
2750	5422	4502	3691	3024	2496	2110	1785	1444	1090
3000	5465	4535	3713	3042	2510	2127	1800	1470	1120
3500		4593	3753	3070	2540	2151	1822	1510	1170
4000		4655	3792	3095	2568	2183	1850	1532	1210
4500		4714	3830	3118	2600	2200	1880	1555	1249
5000		4782	3869	3145	2625	2229	1900	1579	1280

Reference 9

TABLE 5

VISCOSITY OF LIQUID N_2O_4 AT TEMPERATURE BELOW 50 °F

Temperature		Centipoise
°C	°F	
10	50	0.57476
0	32	0.63169
-10	14	0.69864
-20	-4	0.77853*

*Super-cooled

TABLE 6

HEAT CAPACITY OF N_2O_4

Temperature °R	BTU/°F/lb
36.2	0.0221
54.2	0.0490
72.2	0.0746
90.2	0.0947
108.2	0.1110
126.2	0.1247
144.2	0.1367
162.2	0.1478
180.2	0.1579
198.2	0.1669
216.2	0.1757
234.2	0.1837
252.2	0.1916
270.2	0.1995
288.2	0.2072
306.2	0.2147
324.2	0.2224
342.2	0.2302
360.2	0.2382
378.2	0.2463
396.2	0.2544
414.2	0.2625
432.2	0.2705
450.2	0.2785
468.2 solid	0.2865
486.2 liquid	0.3579
504.2	0.3617
522.2	0.3664

Reference 9

TABLE 7

EQUILIBRIUM VALUES - PERCENT DISSOCIATION OF N_2O_4

$$N_2O_4 \rightleftharpoons 2NO_2$$

Temperature		Total Pressure — psia		
°C	°F	7.4	14.7	29.4
20	68	19.5	15.8	7.2
40	104	38.7	31.0	15.1
60	140	66.0	50.4	28.2
80	176	85.0	73.8	46.7
100	212	93.7	88.0	66.5

Reference 9

TABLE 8

DENSITY OF LIQUID UDMH VERSUS TEMPERATURE

Temp C	F	Density g/ml	lb/cu ft	Temp C	F	Density g/ml	lb/cu ft
-60.7	-77.6	0.875	54.64	-1.8	31.6	0.816	50.95
-55.0	-67.0	0.8684	54.22	0.0	32.0	0.815	50.89
-50.3	-58.5	0.864	53.95	0.0	32.0	0.8123	50.72
-45.0	-49.0	0.8578	53.56	8.8	47.8	0.805	50.26
-39.3	-38.7	0.854	53.32	10.0	50.0	0.8017	50.06
-35.0	-31.0	0.8483	52.97	13.8	56.8	0.7968	49.75
-30.7	-23.3	0.845	52.76	14.1	57.4	0.799	49.89
-25.0	-13.0	0.8376	52.30	25.0	77.0	0.7861	49.08
-23.8	-10.8	0.840	52.45	25.3	77.5	0.791	49.39
-20.5	-4.9	0.834	52.08	50.0	122.0	0.762	47.58
-15.0	5.0	0.8278	51.69	55.0	131.0	0.757	47.27
-11.1	12.4	0.825	51.51	60.0	140.0	0.752	46.96
-5.0	23.0	0.8176	51.05				

Reference 2

TABLE 9

VAPOR PRESSURE OF UDMH VERSUS TEMPERATURE

Temp °C	°F	Pressure mm Hg	psia	Temp °C	°F	Pressure mm Hg	psia
-35.41	-31.7	3.51	0.0679	25.6	78.0	168.5	3.259
-23.33	-10.0	8.92	0.1725	30.0	86.0	207.0	4.003
-17.37	2.0	13.62	0.2634	35.0	95.0	256.8	4.967
-13.13	8.8	18.20	0.3519	40.0	104.0	321.4	6.216
-4.12	25.0	32.29	0.6245	45.1	113.2	399.1	7.719
-2.07	28.5	36.65	0.7088	50.2	122.4	491.0	9.496
5.06	41.1	55.62	1.076	54.4	129.9	574.5	11.11
9.76	49.5	72.07	1.394	59.1	138.4	681.6	13.18
15.21	59.4	96.39	1.864	61.7	143.0	749.0	14.49
19.94	67.8	122.40	2.367	62.2	144.0	760.0	14.70
				130.0	266.0	6,360.0	123.0
				160.0	320.0	10,500.0	203.1
				190.0	374.0	16,040.0	310.2
				220.0	428.0	27,110.0	524.3
				230.0	446.0	32,860.0	635.5
				235.0	455.0	35,960.0	695.5
				240.0	464.0	37,410.0	723.5
				250.0	482.0	40,660.0	786.4 critical

Reference 2

TABLE 10

VISCOSITY OF UDMH VERSUS TEMPERATURE

Temp °C	°F	Density g/ml	Kinematic Viscosity/ centistokes	Absolute Viscosity/ centipoises
-55	-67	0.8684	5.889	5.114
-45	-49	0.8578	3.588	3.078
-35	-31	0.8483	2.389	2.026
-25	-13	0.8376	1.745	1.462
-15	5	0.8278	1.338	1.108
- 5	23	0.8176	1.074	0.878
0	32	0.8123	0.964	0.783
10	50	0.8017	0.805	0.645
14	57	0.7968	0.754	0.601

TABLE 10 (CONT)

Temp °C	F	Density g/ml	Kinematic Viscosity/ centistokes	Absolute Viscosity/ centipoises
25	77	0.7861	0.647	0.509
38	100	0.7754	0.533	0.413
44	111	0.7679	0.498	0.382
49	120	0.7588	0.469	0.356
54	129	0.7577	0.443	0.336
60	140	0.7517	0.421	0.316

Reference 2

TABLE 11
HEAT CAPACITY OF UDMH

Temp K	R	Molar Heat Capacity cal/°C/mole	BTU/ °F/lb	Temp K	R	Molar Heat Capacity cal/°C/mole	BTU/ °F/lb
13	23.4	0.65	0.0108	145	261	16.255	0.2709
14	25.2	0.805	0.0134	150	270	16.675	0.2779
15	27.0	0.95	0.0158	155	279	17.10	0.2850
16	28.8	1.105	0.0184	160	288	17.515	0.2919
17	30.6	1.28	0.0213	165	297	17.93	0.2988
18	32.4	1.46	0.0243	170	306	18.33	0.3055
19	34.2	1.64	0.0273	175	315	18.735	0.3123
20	36.0	1.82	0.0303	180	324	19.12	0.3187
21	37.8	2.00	0.0333	185	333	19.55	0.3258
22	39.6	2.18	0.0363	190	342	19.97	0.3328
23	41.4	2.36	0.0393	195	351	20.42	0.3403
24	43.2	2.535	0.0423	200	360	20.88	0.3480
25	45.0	2.72	0.0453	205	369	21.36	0.3560
30	54.0	3.74	0.0623	210	378	21.87	0.3645
35	63.0	4.71	0.0785	215	387	22.36	0.3727
40	72.0	5.56	0.0927	215.951	388.7	22.46	0.3743
						Crystal	
45	81.0	6.345	0.1058		Fusion		
50	90.0	7.09	0.1182				
55	99.0	7.76	0.1293	215.951	388.7	36.25	0.6042
						Liquid	
60	108.0	8.32	0.1387	220	396	36.43	0.6072
65	117.0	8.91	0.1485	225	405	36.65	0.6108
70	126.0	9.48	0.1580	230	414	36.86	0.6143

TABLE 11 (CONT)

Temp F	°R	Molar Heat Capacity cal/°C/mole	BTU/ °F/lb	Temp °K	°R	Molar Heat Capacity cal/°C/mole	BTU °F/lb
75	135.0	10.01	0.1668	235	423	37.08	0.6180
80	144.0	10.54	0.1757	240	432	37.26	0.6210
85	153.0	11.055	0.1843	245	441	37.44	0.6240
90	162.0	11.505	0.1918	250	450	37.60	0.6267
95	171.0	11.94	0.1990	255	459	37.76	0.6293
100	180.0	12.385	0.2064	260	468	38.00	0.6333
105	189.0	12.815	0.2136	265	477	38.07	0.6345
110	198.0	13.255	0.2209	270	486	38.23	0.6372
115	207.0	13.68	0.2280	275	495	38.40	0.6400
120	216.0	14.12	0.2353	280	504	38.59	0.6432
125	225.0	14.555	0.2426	285	513	38.78	0.6463
130	234.0	14.99	0.2498	290	522	38.95	0.6492
135	243.0	15.42	0.2570	295	531	39.11	0.6518
140	252.0	15.84	0.2640	298.16	536.6	39.21	0.6535

Reference 2

TABLE 12

DENSITY OF N_2H_4

Temperature F	C	Density lb/cu ft	g/cc
32	0	64.009	1.0253
59	15	63.31	1.014
68	20	62.961	1.0085
77	25	62.711	0.0045
95	35	62.149	0.9955
122	50	61.188	0.9801

Reference 7

TABLE 13

SPECIFIC GRAVITY $\left[\text{F}/39\ \text{F}\ (4\ \text{C}) \right]$ OF ANHYDROUS N_2H_4 AT TEMPERATURES ABOVE 122 F

| Temperature | | Specific |
C	F	Gravity
50	122	0.9828
60	140	0.9730
70	158	0.9675
80	176	0.9575
90	194	0.9473
100	212	0.9405
110	230	0.9320

TABLE 14

VAPOR PRESSURE OF ANHYDROUS N_2H_4

| Temperature | | Pressure | | Temperature | | Pressure | |
°F	°C	psia	mm Hg	°F	°C	psia	mm Hg
68.37	20.21	0.2011	10.4	167.49	75.27	3.407	176.2
69.08	20.60	0.2069	10.7	168.82	76.01	3.562	184.2
74.60	23.67	0.2398	12.4	185.68	85.38	5.240	271.0
74.71	23.73	0.2436	12.6	190.76	88.20	5.971	308.8
78.84	26.02	0.2823	14.6	205.57	96.43	8.065	417.1
83.91	28.84	0.2920	15.1	214.99	101.66	9.711	502.2
85.73	29.85	0.3539	18.3	226.13	107.85	11.91	615.9
100.20	37.89	0.5453	28.2	232.39	111.33	13.46	696.3
109.98	43.32	0.7367	38.1	237.47	114.15	14.70	760.0
119.26	48.48	0.9727	50.3	284.0	140.0	33.8[a]	1748.0[a]
119.48	48.60	0.9823	50.8	338.0	170.0	73.5[a]	3800.0[a]
135.34	57.41	1.510	78.1				
150.13	65.63	2.204	114.0				
154.08	67.82	2.462	127.3				
158.07	70.04	2.740	141.7				

a = calculated data.

Reference 7

TABLE 15.

VISCOSITY OF ANHYDROUS N_2H_4

Temperature		Viscosity	
°F	°C	lb/ft-sec	centipoises
32	0	0.000883	1.314
35.6	2	0.0008548	1.272
41	5	0.0008111	1.207
50	10	0.0007513	1.118
59	15	0.0007016	1.044
68	20	0.0006543	0.9736
77	25	0.0006081	0.9049
122	50	0.000439	0.653
160	71	0.000339	0.504

Reference 7

TABLE 16

HEAT CAPACITY OF LIQUID N_2H_4

Temperature			Heat Capacity, C_p (liq)	
°F	°K	°C	Btu/lb-°F	cal/g mole-°C
35.04	274.85	1.69	0.728	23.29
44.6	280.2	7.0	0.730	23.37
62.6	290.2	17.0	0.735	23.51
77.0	298.2	25.0	0.738	23.62
80.6	300.2	27.0	0.739	23.65
98.6	310.2	37.0	0.744	23.80
116.6	320.2	47.0	0.749	23.96
134.6	330.2	57.0	0.754	24.14
152.6	340.2	67.0	0.761	24.34

Reference 7

TABLE 17

EFFECT OF CO, CO_2 AND O_2 ON PROPELLANT DECOMPOSITION

Propellant	Gas	Flow Rate Ft.^{3}/Min.	Temperature of Test	Total Gas Vol. Ft.^{3}	Analysis Before Weight %	Analysis After Weight %	Remarks
UDMH	CO	2.2	Ambient	22.0	100.00	99.95	No discoloration or temperature increases noted.
UDMH	CO	2.2	150 F	22.0	100.00	100.00	No discoloration or temperature increases noted.
UDMH	O_2	2.2	Ambient	22.0	100.00	96.07	Orange color by end of test.
N_2H_4	CO	2.2	Ambient	22.0	96.0	96.00	No discoloration or temperature increases noted.
N_2H_4	CO	2.2	200 F	22.0	97.84	97.43	No discoloration or temperature increases noted.
N_2H_4	O_2	2.2	Ambient	22.0	96.00	94.46	No discoloration or temperature increases noted.
N_2O_4	CO	2.2	70 F	22.0	99.80	99.80	No apparent change.
N_2H_4	CO_2	2.2 (Approximately)	Ambient	-	97.84	-	Test terminated almost immediately because of precipitate formation. Accordingly, total gas volume and final analysis not determined.

TABLE 18

EFFECT OF CONTAMINANTS ON PROPELLANT DECOMPOSITION
AT AMBIENT TEMPERATURE

Weight % Contaminant	Propellant Analysis, Wt. %		
	0 Days	17 Days	24 Days
	UDMH		
0.6 Aluminum, 6061-T6	99.8	97.3	96.3
1.3	99.8	97.3	96.4
1.9	99.8	97.6	97.5
Blank	99.8	98.0	96.3
0.6 Stainless Steel 347	99.8	97.2	96.2
1.3	99.8	98.4	96.7
1.9	99.8	97.5	96.7
Blank	99.8	98.0	96.3
0.3 Lint	99.8	98.8	95.9
0.5	99.8	97.9	96.3
0.8	99.8	98.6	96.9
Blank	99.8	98.0	96.3
	N_2H_4		
0.5 Aluminum, 6061-T6	97.5	96.8	94.0
1.0	97.5	96.0	93.4
1.5	97.5	97.5	94.3
Blank	97.5	96.2	93.9
0.5 Stainless Steel 347	97.5	94.7	94.5
1.0	97.5	94.9	94.7
1.5	97.5	94.7	93.8
Blank	97.5	96.2	93.9
0.2 Lint	97.5	97.0	94.3
0.4	97.5	95.7	93.9
0.6	97.5	96.7	93.9
Blank	97.5	96.2	93.9

TABLE 19

EFFECT OF CONTAMINANTS ON PROPELLANT
DECOMPOSITION AT ELEVATED TEMPERATURE (160 F)

Weight % Contaminant	Propellant Analysis, Wt. % UDMH	
	0 Days	7 Days
1.5 Aluminum, 6061-T6	100	97.47
1.5 Stainless Steel 347	100	97.60
0.5 Lint	100	97.60
Blank	100	97.62
	N_2H_4	
1.5 Aluminum, 6061-T6	97.8	97.8
1.5 Stainless Steel 347	97.8	97.0
0.5 Lint	97.8	97.7
Blank	97.8	97.8

TABLE 20

EFFECT OF CONTAMINANTS ON PROPELLANT DECOMPOSITION AT 40 F

Weight % Contaminant	Propellant Analysis, N_2O_4					
	0 Days		7 Days		17 Days	
	% H_2O	% Total Solids	% H_2O	% Total Solids	% H_2O	% Total Solids
0.3 Aluminum, 6061-T6	0.07	< 0.001	0.06	-	0.08	< 0.001
0.7	0.07	< 0.001	0.07	-	0.07	< 0.001
1.0	0.07	< 0.001	0.07	-	0.07	< 0.001
Blank	0.07	< 0.001	0.07	-	0.07	< 0.001
0.3 Stainless Steel 347	0.02	< 0.001	0.03	-	0.03	< 0.001
0.7	0.02	< 0.001	0.03	-	0.03	< 0.001
1.0	0.02	< 0.001	0.03	-	0.03	< 0.001
Blank	0.02	< 0.001	0.03	-	0.03	< 0.001
0.5 Lint	0.06	< 0.001	0.07	< 0.001	Test Terminated at 7 Days	

TABLE 21

EFFECT OF CONTAMINANTS ON PROPELLANT DECOMPOSITION AT 70 F

Weight % Contaminant	Propellant Analysis, N_2O_4			
	0 Days		7 Days	
	% H_2O	% Total Solids	% H_2O	% Total Solids
1.0 Al 6061 — T6	0.06	0.000	0.07	0.000
1.0 SS 347	0.06	0.000	0.08	0.000
0.5 Lint	0.06	0.000	*	0.007
Blank	0.06	0.000	0.06	0.000

*Lint interfered with analysis.

TABLE 22

SHOCK SENSITIVITY TEST OF UDMH, N_2H_4, AND REFERENCE MATERIALS

Material Tested	Volume of Tube After Firing cc	Volume Increase cc	Firing C	Temp F
	A-Series			
Air	166	13	20	68
H_2O	200	47	15	59
	205	52	50	122
	206	53	92	198
Benzene	223	70	50	122
	B-Series			
UDMH	210	57	53	127
Hydrazine Hydrate (54.5% N_2H_4)	216	63	90	194
Hydrazine (98.8%)	220	67	90	194
Methyl Acetylene	232	79	-26	-15
Ethylene Oxide	318**	165	3	27
Nitromethane	***	***	20	68

* Initial Volume of Tube - 153 cc

** Considerable Energy Release

*** Complete Detonation

TABLE 23

N_2H_4 DETONATION TESTS

Material	Reaction Temperature	Pressure Rise	Temperature Rise	Type of Reaction
99.3% N_2H_4	300-600°F	3000 psia max.	Up to 500°F	Detonation
89% N_2H_4 11% H_2O	400-700°F	2000 psia max.	Up to 400°F	Detonation
92% N_2H_4 8% UDMH	300°F	7000 psi	200° pressure	Detonation
90% N_2H_4 10% UDMH	None to 500°F	None	None	None
84% N_2H_4 16% UDMH	None to 500°F	None	None	None
79% N_2H_4 21% UDMH	365°F	500 psi	80°F	Very slow decomposition (0.2 sec)
72% N_2H_4 28% UDMH	None to 500°F	None	None	None
56% N_2H_4 44% UDMH	300°F	Slight	100°F	Very slow decomposition (2 to 4 sec)
30% N_2H_4 70% UDMH	None to 400°F	None	None	None
UDMH	None to 600°F	None	None	None

Reference 19

TABLE 24

TEMPERATURE LIMITS TEST CONDITIONS

Alloy	Propellant	Test Temp. F	Vapor Press. psia at Test Temp.
6061	N$_2$H$_4$ 20% ullage	300 ± 10	40
6061	N$_2$H$_4$ 40% ullage	300 ± 10	40
347	N$_2$H$_4$ 20% ullage	300 ± 10	40
347	N$_2$H$_4$ 40% ullage	300 ± 10	40
PH 15-7 Mo	N$_2$H$_4$ 20% ullage	300 ± 10	40
PH 15-7 Mo	N$_2$H$_4$ 40% ullage	300 ± 10	40
Ti (C 120 AV)	N$_2$H$_4$ 20% ullage	300 ± 10	40
Ti (C 120 AV)	N$_2$H$_4$ 40% ullage	300 ± 10	40
6061	UDMH 25% ullage	300 ± 10	170
6061	UDMH 45% ullage	300 ± 10	170
347	UDMH 25% ullage	300 ± 10	170
347	UDMH 45% ullage	300 ± 10	170
PH 15-7 Mo	UDMH 25% ullage	300 ± 10	170
PH 15-7 Mo	UDMH 45% ullage	300 ± 10	170
Ti (C 120 AV)	UDMH 25% ullage	300 ± 10	170
Ti (C 120 AV)	UDMH 45% ullage	300 ± 10	170
6061	N$_2$O$_4$ 30% ullage	270 ± 10	864
347	N$_2$O$_4$ 30% ullage	270 ± 10	864
PH 15-7 Mo	N$_2$O$_4$ 30% ullage	270 ± 10	864
Ti (C 120 AV)	N$_2$O$_4$ 30% ullage	270 ± 10	864

TABLE 25

TEMPERATURE LIMITS - ELEVATED TEMPERATURE TEST - N_2H_4 AT 300° F

Tank Time	6061-T6 Aluminum Benson Tank		C 120 AV Titanium Benson Tank		PH 15-7 Mo SS Benson Tank	
	T° F	Psig	T° F	Psig	T° F	Psig
0900	58	0	59	0	58	0
1030	124	0	168	0	178	0
1130	194	0	219	0	228	0
1212	228	30.4	295	49.2	298	50
1213	-	-	-	-	Exploded after 3 hours 13 minutes	

TABLE 26

TEMPERATURE LIMITS TEST — ANALYSIS OF N_2H_4, 24-HR, 300 F TESTS

Stock	PH 15-7 Mo	Tank Material 6061-T6	C 120 AV Ti	Mil. Spec.	Remarks
% Conc. 97.04	-	96.30	97.00	95.0 Min.	PH 15-7 Mo tank was destroyed - max pressure recorded was 50 psig - initial test
% Conc. 97.04	-	95.7	95.22	95.0 Min.	PH 15-7 Mo was not used - second test

TABLE 27

TEMPERATURE LIMITS TEST – UDMH TESTS AT 300°F ± 10°F

Elapsed Time Days	PH 15-7 Mo Stainless Steel				C 120 AV Titanium				347 Stainless Steel				6061-T6 Aluminum				Remarks
	25% F	Ullage psig	45% F	Ullage psig	25% F	Ullage psig	45% F	Ullage psig	25% F	Ullage psig	45% F	Ullage psig	25% F	Ullage psig	45% F	Ullage psig	
3	-	112	285	125	285	121	285	125	285	121	285	115	285	115	285	112	Test started 3 March 1960
5	-	131	289	140	286	126	289	129	290	119	286	109	290	122	286	108	Leaks detected later in day larger teflon seals installed
14	-	173	300	175	292	142	285	147	292	150	292	137	295	138	290	124	Test shut down for Week End
20	-	161	269	120	276	118	269	113	273	122	273	106	273	106	264	92	Leaks detected, butyl rubber seals installed, samples taken on 28th day
32	276	138	292	162	282	124	285	124	292	138	290	128	292	133	290	125	
39	276	178	292	187	290	136	292	133	292	158	292	143	285	127	295	146	
42	285	202	295	204	295	147	302	137	295	167	295	153	295	128	300	152	Test shut down for week end
52	282	250	295	250	293	157	295	177	293	193	293	170	285	143	295	175	
63	276	215	290	177	280	164	290	177	290	192	282	177	280	153	290	174	Tests shut down to re-move cycle tests
73	286	230	300	250	292	179	300	192	300	205	300	192	290	165	302	195	
83	290	260	305	263	300	185	305	195	305	220	305	202	298	168	305	195	
91	269	250	282	220	279	170	282	175	279	203	279	183	272	150	282	180	Test terminated on 93rd day

TABLE 28

TEMPERATURE LIMITS TEST —
UDMH ANALYSES FOR 300°F ±10°F

Analysis of Stock at 0 Days

	Sample	Purchase Specification
Distillation Range		
10% Point	144.6°F	143.°F (min)
90% Point	146.6°F	148°F (max)
Specific Gravity 77°F/39°F	0.785	0.783 - 0.786
UDMH Content	99.99%	98% (min)
Melting Point	-71°F	-70°F (max)
Water Content	0.08%	0.3% (max)

Tank Analyses at 28 Days

Tank Material	Ullage	Melting Point	Water Content*
15-7 PH Stainless Steel	25%	-74.0°F	0.3%
15-7 PH Stainless Steel	45%	-75.5°F	0.3%
6A1-4V Titanium	25%	-71.5°F	0.3%
6A1-4V Titanium	45%	-74.0°F	0.1%
347 Stainless Steel	25%	-74.0°F	0.4%
347 Stainless Steel	45%	-75.0°F	0.2%
6061-T6 Aluminum	25%	-72.0°F	0.2%
6061-T6 Aluminum	45%	-72.0°F	0.3%

*By Spectral Analysis in Near Infrared

TABLE 29

TEMPERATURE LIMITS TEST —
UDMH ANALYSIS FOR 300 F TESTS AFTER THREE MONTHS

Tank Material	Ullage %	Distillation Range 10% F	90 F	Sp. Gravity at 77/39 F	UDMH Content %	Melting Point F	Water Content %	Appearance
Specification		143.0 Min	148.0 Max	0.763/0.786	98.0 Min	-70 Max	0.3 Max	Colorless
PH 15-7 Mo Stainless Steel	25	135.9	147.9	0.7781	-	-80	0.27	Straw Color
PH 15-7 Mo Stainless Steel	45	135.9	149.2	0.7766	-	-80	0.44	Straw Color
6A1-4V Titanium	25	142.5	146.5	0.7831	-	-78	0.07	Straw Color
6A1-4V Titanium	45	142.5	146.5	0.7842	-	-76	0.07	Straw Color
347 Stainless Steel	25	139.1	147.4	0.7808	-	-77.5	0.19	Straw Color
347 Stainless Steel	45	138.4	150.6	0.7813	-	-81	0.63	Straw Color
6061-T6 Aluminum	25	140.4	147.2	0.7824	-	-74	0.17	Straw Color
6061-T6 Aluminum	45	141.4	147.2	0.7845	-	-77.5	0.17	Straw Color

TABLE 30

TEMPERATURE LIMITS TEST – N_2O_4 TESTS AT 270° F ±10° F

Elapsed Time Days	PH 15-7 Mo SS F	psig	347 SS F	psig	6061-T6 Al F	psig	Remarks
5	279	640	276	620	272	580	Test 10 February 1960 Initial Ullage 30%
9	277	810	271	720	265	670	Tests Shut Down for Week End
16	271	800	268	700	267	690	Tests Shut Down for Week End
23	279	830	273	740	261	630	Tests Shut Down for Week End
30	277	810	271	700	263	645	Tests Shut Down for Week End
37	273	805	267	680	264	680	Tests Shut Down for Week End
44	275	820	269	710	265	670	Tests Shut Down for Week End
51	274	810	269	710	264	680	Tests Shut Down for Week End
58	274	800	270	730	264	680	Tests Shut Down for Week End
65	273	800	270	710	263	670	Tests Shut Down for Week End
72	273	800	270	710	262	670	Tests Shut Down for Week End
79	273	800	273	720	263	670	Tests Shut Down for Week End
89							Tests Completed

TABLE 31

TEMPERATURE LIMITS TEST – N_2O_4 ANALYSIS FOR 270° F TESTS

Procurement Spec.	Concentration 99.5 wt. % Min	H_2O 0.1 wt. % Max	Non-Volatile 0.01 wt. Max	Comments
0 Days	99.7	0.01	'	
		89th Day		
6061-T4 Tank	99.7	0.07	01	
PH 15-7 Mo Tank	99.7	0.04	1	
347 SS Tank	99.5	0.01	0.	
C 120 AV Ti. Tank	-	0.07	-	After one day

TABLE 32

TEMPERATURE LIMITS TEST — UDMH AND N_2H_4 AT -65° F TESTS

N_2H_4 20% ULLAGE

Days	PH 15-7 Mo SS Tank °F	Psig	347 SS Tank °F	Psig	6061-T6 Al Tank °F	Psig	C 120 AV Ti Tank °F	Psig	Remarks
0									Start
1									Refrigeration system down for repairs
7									Resumed tests
8	-48	0	-47	0	-48	0	-49	0	
14	-60	0	-58	0	-59	0	-62	0	
20	-60	0	-57	0	-59	0	-62	0	
26	-64	0	-61	0	-63	0	-67	0	
30	-68	0	-67	0	-69	0	-73	0	Test completed - fuel left in tanks until after vacation period (2 weeks). Samples then taken for analysis

UDMH 25% ULLAGE

Days	PH 15-7 Mo SS Tank °F	Psig	347 SS Tank °F	Psig	6061-T6 Al Tank °F	Psig	C 120 AV Ti Tank °F	Psig	Remarks
0									Start
1									Refrigeration system down for repairs
7									Resumed tests
8	-44	0	-47	0	-47	0	-46	0	
14	-56	0	-60	0	-59	0	-58	0	
20	-55	0	-56	0	-57	0	-59	0	
26	-59	0	-63	0	-62	0	-64	0	
30	-65	0	-69	0	-69	0	-68	0	Test completed - fuel left in tanks until after vacation period (2 weeks). Samples then taken for analysis

TABLE 33

TEMPERATURE LIMITS TEST —
FUEL ANALYSIS FOR -65° F TESTS

Distillation Range °F	UDMH		N_2H_4	
	0 Days	Specification	0 Days	Specification
10% Point	144.8	143 F min.	-	-
90% Point	146.8	148° F max.	-	-
Density gm/cc	0.785	0.783/0.786	-	-
Concentration, wt %	-	98.0 min.	96.28	95.0 min.
Melting Point, F	-	-70 F max	-	-
Water Content, wt %	0.11	0.3 max	-	-

UDMH ANALYSIS AFTER LOW TEMPERATURE TEST

Tank Material	PH 15-7 Mo	347 SS	6061-T6	C 120 AVTi
Distillation Range F				
10% Point	144.7	144.7	144.7	144.7
90% Point	146.5	146.5	146.9	146.5
Density gm/cc	0.784	0.784	0.784	0.784
Concentration, wt %	-	-	-	-
Melting Point. °F	-	-	-	-
Water Content, wt %	0.07	0.07	0.13	0.07

N_2H_4 ANALYSIS AFTER LOW TEMPERATURE TEST

Tank Material	347 SS	6061-T6	PH 15-7 Mo	C 120 AV Ti
Concentration, wt %	96.20	96.28	96.30	96.20
Density gm/cc	1.007	1.007	1.008	1.008

TABLE 34

TEMPERATURE LIMITS TESTS —
N_2O_4 ANALYSIS FOR -20° F TESTS

	Specification	0 Days	30 Days		
			6061-T6	347 SS	PH 15-7 Mo SS
N_2O_4 Concentration, Wt. %	99.50 (Min.)	99.7	-	-	-
Chloride Content as NOCl. Wt. %	0.08 (Max.)	-	-	-	-
Water Content, Wt. %	0.10 (Max.)	0.08	.16	.15	.15
Non Volatile, Wt. %	0.01 (Max.)	< 0.001	< 0.001	< 0.001	< 0.001

TABLE 35

TEMPERATURE CYCLE TESTS WITH N$_2$H$_4$
(Ranging from -100° F to 300° F)

Elapsed Time Days	347 Stainless Steel				6061-T6 Aluminum				C 120 AV Titanium			
	20% Ullage		40% Ullage		20% Ullage		40% Ullage		20% Ullage		40% Ullage	
	°F	psig	°F	psig	°F	psig	°F	psig	°F	psig	°F	psig
0	-43	0	-49	0	0	0	-56	0	-34	0	-36	0
3	277	40	299	57	298	42	291	40	289	52	270	38
6	-38	0	-42	0	-38	0	-43	0	-39	0	-37	0
12	309	56	292	51	309	51	302	55	301	61	298	50
17	-82	0	-81	0	-81	0	-81	0	-80	0	-80	0
21	288	53	302	52	302	47	295	55	295	58	288	45
25	-64	0	-70	0	-17	0	-39	0	-42	0	-42	0
27	-80	0	-58	0	-70	0	-2C	0	-83	0	-125	0
28	306	59	295	54	306	43	299	56	288	45	299	65
31	-67	0	-44	0	-38	0	-105	0	-42	0	-30	0
32	292	56	302	61	302	54	299	52	299	60	288	51
35	-67	0	-81	0	-64	0	-76	0	-64	0	-53	0
38	273	50	299	63	306	56	292	60	273	58	288	57
41*	-80	0	-70	0	-60	0	-70	0	-70	0	-50	0

* Test Complete

TABLE 36

ANALYSIS OF N$_2$H$_4$ FROM TEMPERATURE CYCLE TESTS

	Specification	0 Days	347 Stainless Steel		6061-T6 Aluminum		C 120 AV Titanium	
			20% Ull.	40% Ull.	20% Ull.	40% Ull.	20% Ull.	40% Ull.
			6 Weeks		6 Weeks		6 Weeks	
N$_2$H$_4$ Conc. % by weight	95.0	97.0	96.8	96.9	96.4	96.9	96.1	96.5
Sp. Gr.	1.004 .002	1.006	1.0069	1.0065	1.0070	1.00C5	1.0064	1.0050

TABLE 37

TEMPERATURE CYCLE TESTS WITH UDMH

Elapsed Time Days	PH 15-7 Mo Stainless Steel				C 120 AV Titanium				347 Stainless Steel				6061-T6 Aluminum				Remarks
	25% °F	Ullage psig	45% °F	Ullage psig	25% °F	Ullage psig	45% °F	Ullage psig	25% °F	Ullage psig	45% °F	Ullage psig	25% °F	Ullage psig	45% °F	Ullage psig	
3	318	160	318	170	318	157	318	157	318	163	318	157	318	170	318	185	Test started 3 March 1960
4	-23	0	-26	0	-23	0	-23	0	-23	0	-25	0	-25	0	-25	0	
10	300	148	300	162	300	155	300	160	290	142	300	162	300	155	300	162	
13	-36	0	-43	0	-36	7	-40	7	-38	5	-43	5	-38	0	-40	0	
14	279	121	289	132	279	134	286	150	280	123	285	138	290	132	292	134	Test shut down for Week End
17	-36	0	-36	0	-36	6	-35	8	-38	5	-38	5	-38	0	-37	0	
18	279	120	285	130	279	130	279	153	279	123	285	137	285	131	287	135	
20	62	0	62	7	62	11	63	18	60	10	60	10	61	5	62	0	Leaks detected, butyl rubber seals installed. samples taken on 28th day
32	246	88	259	96	243	82	253	97	240	86	256	98	249	89	259	97	
33	-14	0	-15	0	-14	0	-15	0	-18	0	-16	0	-17	0	-15	0	
34	285	144	292	152	285	141	292	164	285	140	292	156	292	151	295	156	
35	5	0	8	0	4	0	9	5	-6	3	6	6	-2	0	2	0	Tests shut down for Week End
42	272	122	279	127	275	120	279	145	272	116	279	128	279	126	282	130	Tests shut down for Week End
47	-20	5	-18	0	-22	5	-18	10	-26	3	-19	6	-25	0	-22	0	Tests shut down for Week End
48	285	149	292	152	285	152	290	182	285	142	290	153	292	153	292	152	
53	-43	4	-46	0	-42	4	-45	10	-44	3	-47	4	-44	0	-45	0	
56	274	123	275	126	272	127	276	153	272	114	277	124	279	123	279	126	Tests shut down for Week End
63	31	10	34	6	31	12	33	18	26	4	31	6	28	0	30	0	Tests terminated

TABLE 38

UDMH ANALYSES FOR TEMPERATURE CYCLE TESTS

Analysis of Stock at 0 Days

	Sample	Purchase Specification
Distillation Range		
10% Point	144.6°F	143°F (min)
90% Point	146.6°F	148°F (max)
Specific Gravity 77°F/39°F	0.785	0.783 - 0.786
UDMH Content	99.99%	98% (min)
Melting Point	-71°F	-70°F (max)
Water Content	0.08%	0.3% (max)

Tank Analyses at 28 Days

Tank Material	Ullage	Melting Point	Water Content*
PH 15-7 Mo Stainless Steel	25%	-72.5°F	0.3%
PH 15-7 Mo Stainless Steel	45%	-72.0°F	0.2%
6A1-4V Titanium	25%	-72.5°F	0.1%
6A1-4V Titanium	45%	-72.0°F	0.3%
347 Stainless Steel	25%	-70.0°F	0.3%
347 Stainless Steel	45%	-72.0°F	0.4%
6061-T6 Aluminum	25%	-71.0°F	0.3%
6061-T6 Aluminum	45%	-72.0°F	0.4%

*By Spectral Analysis in Near Infrared

TABLE 39

UDMH ANALYSIS FOR TEMPERATURE CYCLE TESTS AFTER TWO MONTHS

Tank Material Specification	Ullage %	Distillation Range 10% F	90% F	Sp. Gravity at 77/39 F	UDMH Content %	Melting Point F	Water Content %	Appearance
		143.0 Min	148 Max	0.783/0.786	98.0 Min	-70 Max	0.3 Max	Colorless
PH 15-7 Mo Stainless Steel	25	144.1	147.3	0.785	-	-73	0.2	Straw Yellow
PH 15-7 Mo Stainless Steel	45	144.1	146.6	0.785	-	-73	0.1	Straw Yellow
C 120 AV Titanium	25	143.5	146.0	0.783	-	-73	<0.1	Straw Yellow
C 120 AV Titanium	45	143.0	145.9	0.783	-	-73	<0.1	Straw Yellow
347 Stainless Steel	25	144.4	146.6	0.785	-	-70	0.1	Straw Yellow
347 Stainless Steel	45	144.4	148.8	0.787	-	-73	0.4	Straw Yellow
6061-T6 Aluminum	25	144.4	147.3	0.783	-	-71	0.1	Straw Yellow
6061-T6 Aluminum	45	144.6	146.6	0.787	-	-72	0.2	Straw Yellow

TABLE 40

TEMPERATURE CYCLE TESTS WITH N₂O₄ AT 30% ULLAGE
(Ranging from -20 to 270 F)

Elapsed Time Days	PH 15-7 Mo Stainless Steel		347 Stainless Steel		6061-T6 Aluminum	
	F	psig	F	psig	F	psig
1	246	480	246	490	243	460
6	0	0	-1	0	0	0
7	266	620	269	640	259	580
10	18	0	21	0	17	0
17	273	700	273	690	269	690
23	-17	0	-14	0	-15	0
24	253	530	251	490	243	480
28	-23	0	-29	0	-27	0
29	266	650	278	580	260	600
34	-42	0	-49	0	-12	0
37	286	800	786	720	285	850
38	-23	0	-23	0	-20	0
41	277	765	277	740	270	725
42*	-26	0	-36	30	-25	0

* Test Terminated

TABLE 41

N₂O₄ ANALYSIS FOR -20 TO 270 F TESTS

	Concentration	H₂O	Non Volatile
Procurement Spec.	99.5 min.	0.1 max.	0.01 max.
0 Days	99.7	0.01	<0.01
Six Weeks			
PH 15-7 Mo Tank	99.7	0.05	0.003
347 SS Tank	99.6	0.09	<0.001
C 120 AV Ti. Tank	99.7	0.05	0.002

TABLE 42

TEMPERATURE LIMITS TEST —
N_2O_4 AT 90 F TO 150 F IN TITANIUM TANK (C 120 AV)

Day	F	Psig	Remarks
0			Tank was filled to 50% ullage, heating started.
0	151	82.3	
1	96	13.4	
1	123	37.0	
			Week End
4	91	2.1	
4	119	78.2	
5	98	32.8	
5	109	12.3	
6	93	61.6	
6	108	41.1	
7	111	38.0	
7	132	155.2	Taber Malfunctioned
8	60		Pressure Pick Up Discontinued
25	126		During two weeks shutdown - exposed to outdoor temperatures (100 to 65 F)
26	108		
27	96		
27	120		Test Complete
28	105		Dropped 50 lb. from height of 2 feet, No Explosion, Disconnected Tank, Unloaded N_2O_4. Inspected inside of tank - no corrosion or deposit formation detected.

TABLE 43

TEMPERATURE LIMITS TEST — ANALYSIS OF
N_2O_4 90 F TO 150 F FROM TITANIUM TANK

	Sample		Vendor
Composition Wt. %	Before	After	Specification
N_2O_4	99.5	99.5	99.5 min.
H_2O Equivalent	0.04	0.05	0.1 max.
Non-Volatile (Ash)	0.002	0.002	0.01 max.

TABLE 44

LITERATURE SURVEY — COMPATIBILITY OF VARIOUS METALS WITH N_2O_4

Metal	Temp., F	Corrosion, mpy	Remarks	Reference
Pure Aluminum	Room	-	Satisfactory	23
2024 Aluminum	140	0.9	Satisfactory	23,25
2024 Aluminum	-	-	Unsatisfactory	68
4043 Aluminum	Room	-	Satisfactory	23
5052 Aluminum	140	1.5 (0.5% H_2O)	Satisfactory	23,25
6061 Aluminum	130	0.3	Satisfactory	23,25
356 Aluminum	-	-	Satisfactory	68
8630 Steel	140	0.04	Satisfactory	25
C1020 Steel	130	0.6	Satisfactory	23,25
Carpenter 16-25-6	-	-	Satisfactory	29
303 Stainless Steel	77	<0.2	Satisfactory	23
304 Stainless Steel	140	0.04	Satisfactory	25
347 Stainless Steel	130	0	Satisfactory	23,25
400 Stainless Steel	-	-	Satisfactory	29
Tin	77	1.0	Satisfactory	23
Titanium 6Al + 4V (C120AV)	160	0.1	Satisfactory	23
Monel + "K" Monel	77	2.0	Satisfactory	9,23
"K" Monel	-	-	Unsatisfactory	68
Inconel	Room	-	Satisfactory	29
Stellite 21	Room	-	Satisfactory	29
Hastelloys	Room	-	Satisfactory	29
Cast Iron	Room	1.0	Satisfactory	25
Nickel	Room	-	Satisfactory	9
Nickel	-	-	Unsatisfactory	68
Cadmium	-	-	Unsatisfactory	68
7075 Aluminum (Specimen in Teflon Vessel)	160	22	Unsatisfactory	23
Brass	Room	-	Unsatisfactory	23,25
Bronze	Room	-	Unsatisfactory	23,25

TABLE 44 (CONT)

Metal	Temp., °F	Corrosion, mpy	Remarks	Reference
Zinc	Room	-	Unsatisfactory	23,25
Copper	Room	-	Short-term service	23,25
Lead	Room	-	Short-term service	23,25
17-7 PH Stainless Steel	Room	-	Short-term service	23
17-7 PH Stainless Steel	-	-	Satisfactory	68
410 Stainless Steel	Room	-	Short-term service	23
Inconel X	-	-	Satisfactory	68
Chrome Plating	-	-	Satisfactory (if no pinholes)	68
Nickel (Electroless)	-	-	Unsatisfactory	68
Silver	-	-	Unsatisfactory	68

TABLE 45

LITERATURE SURVEY --

COMPATIBILITY OF VARIOUS PLASTICS AND ELASTOMERS WITH N_2O_4

Material	Temp. °F	Remarks	Reference
Teflon 100X (FEP)	160	General service	25, 26
Teflon 1 (TFE)	160	As 2nd choice over	26
Kel-F (Unplasticized)	160	Short-term service	26
Polyethylene	Room	Short-term service	25
Koroseal	Room	Short-term service	25
Saran	Room	Short-term service	25
Silastic LS-53	Room	Short-term service	27
Flourel MMM	Room	Short-term service	30
Tygon	Room	Short-term service	25
Genetron VK-240	Room	Not recommended	26
GR-S Co-polymers	Room	Not recommended	27

TABLE 45 (CONT)

Material	Temp. °F	Remarks	References
Buna N Rubber	Room	Not recommended	27
Thiokol 3000ST	Room	Not recommended	27
Kel-F Elastomers	Room	Not recommended	27
Viton A	Room	Not recommended	27
Neoprene W	Room	Not recommended	27
Hypalon 20	Room	Not recommended	27
Adiprene C	Room	Not recommended	27
Butyl, Poly (isobutylene) Enjay 82521	Room	Not recommended	27
Enjay 85250	Room	Not recommended	27
Silastic S-9711, 651, 80, S-2097U	Room	Not recommended	27
Poly FBA-1F4 Fluorobutyl Acrylate Elastomer	Room	Not recommended	27
U.S. Rubber 20995	Room	Not recommended	25
Mylar	Room	Not recommended	31
Polypropylene	Room	Not recommended	22
Nylon	Room	Not recommended	25
Viton B	Room	Short-term service	73

TABLE 46

LITERATURE SURVEY — COMPATIBILITY OF VARIOUS LUBRICANTS,
SEALANTS, AND GASKETS WITH N_2O_4

Material	Use	Remarks	Reference
Fluorolube	Lubricant	Short-term service	29
Nordcoseal 147S	Lubricant	Short-term service	29
Nordcoseal 234S	Lubricant	Short-term service	28
Oxyseal NA-20313	Thread Sealant	Short-term service	29
Molykote Z	Lubricant	Short-term service	24
Molykote Z (without binder)	Lubricant	Satisfactory	68
Hercules Acid-Proof Grease	Lubricant	Short-term service	29

TABLE 46 (CONT)

Material	Use	Remarks	Reference
Fluorthene G	Lubricant	Short-term service	21
APS-C 4.06	Lubricant	Short-term service	21
Teflon Tape	Thread Sealant	Short-term service	32
Teflon Impregnated Asbestos	Packing	Short-term service	28
Johns-Manville Service No. 60	Gasket (Asbestos-graphite)	Short-term service	28
Johns-Manville Service No. 60	Gasket (Asbestos-graphite)	Not recommended	68
Johns-Manville Service No. 76	Gasket	Not recommended	68
DC-11	Lubricant	Short-term service	22
DC-11	Lubricant	Satisfactory	68
DC-55	Lubricant	Unsatisfactory	68
AN 6246 Leather	Gasket	Not recommended	68
Graphite	Lubricant	Satisfactory	68
NA2-20502	Lubricant	Satisfactory	68
Oxylube	Lubricant	Unsatisfactory	68

TABLE 47

LITERATURE SURVEY — COMPATIBILITY OF VARIOUS METALS WITH UDMH

Metal	Temp., °F	Remarks	Reference
1100 Aluminum	160	General service	8,35
3003	86	<0.1 mpy	69
2017	160	Use with caution	8,35
2024	160	Controversy	8,35,69
5052	160	General service	8,35
6061	160	General service	8,35
7075	160	Controversy	8,35,69
356	160	General service	8,35

TABLE 47 (CONT)

Metal	Temp., °F	Remarks	Reference
5086	86	<0.1 mpy	69
2024T3-iridite coated	86	<0.1 mpy	69
Brass Bronze	160	Short-term service	34
Copper	-	Unsatisfactory	23,65
AZ31B Magnesium	130	Satisfactory in Anhydrous UDMH	8,67
AZ61A Magnesium	130	Satisfactory in Anhydrous UDMH	8,67
AZ91C Magnesium	130	Satisfactory in Anhydrous UDMH	8,67
AZ92A Magnesium	130	Satisfactory in Anhydrous UDMH	8,67
ZK60A Magnesium	130	Satisfactory in Anhydrous UDMH	8,67
Mild Steel	140	Satisfactory with N_2 blanket over UDMH	34,65
302 SS	160	General service	34,35,65
303 SS	160	General service	34,35,65
304 SS	160	General service	34,35,65
316 SS	160	Controversy	34,35,65,69,71
321 SS	160	General service	34,35,65
347 SS	160	General service	34,35,65
416 SS	250	General service	35
PH 15-7 Mo	86	<0.1 mpy	69
17-7 PH	86	<0.1 mpy	69
Dow Metal	140	General service	34
Inconel	140	General service	34
Nickel	140	General service	35
Titanium A110-AT	130	General service	67
Titanium C 120 AV	146	<0.1 mpy	69
Cadmium	-	Unsatisfactory	23,34,35
Hastelloy C	-	Controversy	23,34,35,69
Monel	-	Controversy	23,34,35
Zinc	-	Not recommended	65
Molybdenum (pellet)	86	1.2 mpy corrosion rate	69

TABLE 48

LITERATURE SURVEY —

COMPATIBILITY OF VARIOUS PLASTICS AND ELASTOMERS WITH UDMH

Material	Temp °F	Remarks	Reference
Garlock Gasket No. 900	Room	Short-term service	35, 37, 38
Haveg 60	Room	Short-term service	35, 37, 38
Mylar Film No. 750A	Room	Short-term service	35, 37, 38
Nylon	Room	Short-term service	35, 37, 38
Polyethylene, Type III, (high density)	Room	Short-term service	35, 37, 38
Butyl Rubber of many compounds	Room	Short-term service	35, 37, 38
Acid Seal Rubber No. 83123	Room	Short-term service	35
Adiprene B Nol 1156 and No. 1157 (an isocyanate polyester)	Room	Unsatisfactory	35
Chemigum N-6, Uncured (butadiene copolymer)	Room	Unsatisfactory	35
Chemigum SL (isocyanate polyester)	Room	Unsatisfactory	35
Dapon G-81 (Diallyl phathalate)	Room	Unsatisfactory	35
DuVerre 22 (polyester fiberglass)	Room	Unsatisfactory	35
Fluororubber 1F4 (Fluori-nated synthetic rubber)	Room	Short-term service	35
Garlock (Red 22 Rubber)	Room	Short-term service	35
Haveg 30, 41 (phenolic asbestos)	Room	Unsatisfactory	35
Kel-F, Plasticized (chlorotrifluorethylene)	Room	Unsatisfactory	35
Kel-F Elastomer No. 3700	Room	Unsatisfactory	35
Linear "0" Ring No. 1820-13 (Kel-F compound)	Room	Unsatisfactory	35
Kel-F Elastomer No. 5500	Room	Unsatisfactory	69
Hydropol-T (Phillips Petroleum)	86	Recommended	69

TABLE 48 (CONT)

Material	Temp °F	Remarks	Reference
Melbestos (fiberous asbestos)	Room	Unsatisfactory	35
Neoprene (chloroprene rubber), neoprene G91 (white)	Room	Short-term service	35
Phioflex 1006, uncured (Butadiene styrene)	Room	Unsatisfactory	35
Rigid high impact pipe (acrylonitrile-styrene)	Room	Unsatisfactory	35
Buna N Rubber	Room	Unsatisfactory	35
Saran (vinyl chloride-vinylidene copolymer)	Room	Unsatisfactory	35
Silastic 7180 (silicone rubber compound)	Room	Unsatisfactory	35
Silicone Rubber (poly-siloxane)	Roome	Unsatisfactory	35
M. W. Kellog Co. X-300 Rubber	Room	Unsatisfactory	35
Tygon Tubing (vinyl chloride acetate co-polymer)	Room	Unsatisfactory	35
Uscolite	Room	Unsatisfactory	35
Viton A (vinylidene fluoride, perfluoro-propylene copolymer)	Room	Unsatisfactory	35
Thiokol 3000ST	Room	Unsatisfactory	35
DC LS-53 (fluorosilicon rubber)	Room	Unsatisfactory	22
Silicone LS-53	86	Unsatisfactory	69
Viton A - 9653	Room	Unsatisfactory	69
247M	Room	Unsatisfactory	69
44-11	Room	Unsatisfactory	69

TABLE 49

LITERATURE SURVEY —

COMPATIBILITY OF VARIOUS LUBRICANTS WITH SEALS WITH UDMH

Material	Temp °F	Remarks	Reference
Calvacene, Stopcock Grease	-	Unsatisfactory	34, 39, 40, 41
Fluorolube	-	Unsatisfactory	34, 39, 40, 41
Socony-Mobile, General Purpose Grease, BRB No. 1	-	Unsatisfactory	34, 39, 40, 41
Mil 1010, Grease	-	Unsatisfactory	34, 39, 40, 41
Mil 7808C, Oil	-	Unsatisfactory	34, 39, 40, 41
Motor Oil, 20 W	-	Unsatisfactory	34, 39, 40, 41
Molykote, Molybdenum Disulfide	-	Unsatisfactory	34, 39, 40, 41
Nonag, Stopcock Grease	-	Unsatisfactory	34, 39, 40, 41
Nordcoseal 24	-	Unsatisfactory	34, 39, 40, 41
Parkerlube	-	Unsatisfactory	34, 39, 40, 41
Paraline 12-4	-	Unsatisfactory	34, 39, 40, 41
Silicone Stopcock Grease	-	Unsatisfactory	34, 39, 40, 41
Silicone Greases, DC 33 and DC 44	-	Unsatisfactory	34, 39, 40, 41
Rockwell Nordstrom No. 555	-	Unsatisfactory	34, 39, 40, 41
Apiezon L/Graphite (50/50 mixture)	Room	Satisfactory	36
UDM Lube*/Electro Mechanics No. 20057 (50/50 mixture)	0°F-Room	Satisfactory	36
Delanium (graphite with a plastic binder)	Room	Satisfactory	36
Insoluble Pump and Packing Lubricant, Crane Co.	Room	Satisfactory	34
Garlock No. 5210, Asbestos/ Graphite Packing	Room	Satisfactory	34
Q-Seal Pipe Dope (Quigley Co.)	Room	Satisfactory	34
White Lead Pipe Dope (Dutch Boy)	Room	Satisfactory	34
Apiezon L	Room	Limited service	69
Lubriseal (Arthur H. Thomas)	Room	Limited service	69
Nordcoseal 147	Room	Limited service	69
DC11	Room	Unsatisfactory	69

* Superlube Inc., Cleveland Ohio

TABLE 50

LITERATURE SURVEY –

COMPATIBILITY TESTS OF VARIOUS METALS WITH N_2H_4

Material	Temp °F	Time Days	Wt. Percent N_2H_4 Before	After	Ref.	Remarks
Aluminum						
40E	-	-	-	-	68	Not recommended - causes decomposition above 100°F.
1100	75	5	95.07	93.12	43	No apparent effect on specimen.
1100	80	30	95.5	93.5	44	No apparent effect on specimen.
1100	140	30	95.5	91.5	44	No apparent effect on specimen.
3003	80	30	95.5	93.75	44	No apparent effect on specimen.
3003	140	30	95.5	86.5	44	Hydrazine decomposition - use with caution.
2014	80	30	68.0*	-	45	Corrosion negligible 0.19 mil/yr-material satisfactory.
2014	160	30	68.0*	-	45	Corrosion negligible 0.12 mil/yr-material satisfactory.
2014	160	-	-	-	68	Not recommended.
2017	80	30	68.0*	-	45	Corrosion negligible 0.14 mil/yr-material satisfactory.
2017	160	30	68.0*	-	45	Corrosion negligible 0.06 mil, yr-material satisfactory.
2024	80-120	30	OMCC N_2H_4	-	45	Heavy to light brown deposit - use with caution.
2024	80-120	30	OMCC + 0.3% Boric Acid	-	45	At 120°F dull gray film - use with caution.
2024	80-120	30	Fairmont N_2H_4	-	46	Black corrosion.
2024	80-120	30	Fairmont +0.3% Boric Acid	-	46	At 120°F gray film and loose black scale.
2024	80-120	30	Fairmont +HCl	-	46	Gray to light brown film.
2024	80	30	68.0*	-	45	Corrosion negligible 0.63 mil/yr-material satisfactory.
2024	160	30	68.0*	-	45	Corrosion negligible 0.22 mil/yr-material satisfactory.
2024	160	-	-	-	68	Not recommended.
40 E	60-75	2.8	66.0	-	43	Slight corrosion noted, use with caution.
4043	60-75	2.8	66.0	-	43	Surface turned blue.
4043	80	30	68.0*	-	45,47	Corrosion negligible 0.068 mil/yr-material satisfactory.
4043	160	30	68.0*	-	45,47	Corrosion negligible 0.516 mil/yr-material satisfactory.
5052	80	30	68.0*	-	45	Corrosion negligible 0.09 mil/yr-material satisfactory.
5052	ambient	-	-	-	68	Recommended.
6061	80	30	68.0*	-	45	Corrosion negligible 0.10 mil/yr-material satisfactory.
6061	160	30	68.0*	-	45	Corrosion negligible 0.04 mil/yr-material satisfactory.
6066	ambient	-	-	-	68	Recommended.
7075	ambient	-	-	-	68	Not recommended.

TABLE 50 (CONT)

Material	Temp °F	Time Days	Wt. Percent - N_2H_4 Before	After	Ref.	Remarks
Aluminum (Cont'd)						
356	80	30	68.0*	-	45,47	Corrosion negligible 0.24 mil/yr-material satisfactory.
356	160	30	68.0*	-	45,47	Corrosion negligible 0.24 mil/yr-material satisfactory.
716	80	30	95.5	93.5	44	No apparent attack on the material.
716	140	30	95.5	91.0	44	No apparent attack on the material.
Stainless Steel						
302	80	30	95.5	93.5	44	No apparent attack on the sample.
304	80	2.8	66.0	-	43	No apparent effect on the sample.
304	70-80	119-382	95.0	-	48	Slight loss in weight noted for 6 samples.
304	140	30	95.5	91.5	44	No change in sample or hydrazine.
304	80	30	95.5	94.0	44	No change in sample or hydrazine.
304	140	120	95.5	-	44	No change in sample or hydrazine.
316	<160	-	-	-	71	Recommended.
317	80	30	95.5	93.65	44	No apparent effect on sample.
321	68	24	95.6	-	48	Slight pressure rise - .011 atm./day/ml N_2H_4-sealed.
347	80-120	30	Fairmont N_2H_4	-	46	No effect on the sample.
347	80-120	30	Fairmont +0.3% Boric Acid	-	46	No effect on the sample.
430	68	24	5.6	-	48	Slight pressure rise - .01 atm./day/ml $N_2 H_4$ - sealed.
Stainless W	75	6.1	93.23	92.34	43	No effect on sample.
410 SS	80	30	95.5	93.65	44	No effect on sample.
Brass	80	30	95.5	92.0	44,48	Compatible.
Brass	140	30	95.5	91.0	44	Slight attack on specimen
Brass	140	120	95.5	95.0 (approx.)	44,48	Material compatible, negligible decomposition of N_2H_4.
Copper	80	30	95.5	94.5	44	Apparently satisfactory.
Copper	140	30	95.5	68.5	44	Hydrazine decomposed.
Copper	70-73	365	95.1	-	48	Specimen showed monthly weight loss.
Copper	149	240	95.1	-	48	Severe corrosion of specimen.

TABLE 50 (CONT)

Material	Temp °F	Time Days	Wt. Percent N_2H_4 Before	After	Ref.	Remarks
Inconel	68-77	5	95.09	93.58	4,	No apparent effect on the sample.
Inconel	80	30	95.5	93.5	44,48	No apparent effect on the sample.
Inconel X	75	2.8	66.0	-	43	No apparent effect on the sample.
Nickel	80	30	95.5	94.0	44	No apparent effect on the sample.
Nickel	140	30	95.5	71.0	44	No apparent effect on the sample. N_2H_4 decomposes
Nickel	80	30	95.5	93.25	44	No apparent effect on the sample.
Lead	68	24	95.6	-	48	No apparent reaction.
Lead	70-73	22 hrs.	95.1	-	48	Immediate reaction followed by severe corrosion.
Lead	149	minutes	95.1	-	48	Immediate reaction solution turned blue.
Magesium	80	30	95.5	94.0	44	Pressure increase in closed system.
Magnesium	70-73	1	95.1	-	48	Rapid loss of weight.
Molybdenum (sintered)	68-75	5	95.09	92.72	43	Negligible corrosion and weight loss.
Molybdenum (.004" chrome plate)	68-75	7	93.23	93.0	43	No apparent effect on the sample
Molybdenum	80	30	95.5	94.0	44,48	No apparent effect on the sample; some forms of Mo cause decomposition.
Monel	68-75	3.8	97.63	88.07	43	Slight corrosion - hydrazine decomposes.
Monel	68	24	95.6	-	48	No apparent effect on the sample.
Monel	80	30	95.5	94.0	44,48	No apparent effect on the sample.
Nichrome	80	30	95.5	94.0	44,48	No apparent effect on the sample.
Chromel - A	80	30	95.5	92.5	44,48	No apparent effect on the sample, N_2H_4 decomposes.
Silver	80	30	95.5	93.5	44,48	No apparent effect on the sample.
1020 Mild Steel	68-77	3.8	97.63	95.5	43	Visible corrosion masked by rust formed after test.
1020 Mild Steel	70-73	365	95.1	-	48	Weight loss noted after each month, considerable corrosion by the 7th month.
1020 Mild Steel	149	300	95.1	-	48	Wt. loss noted after 5th month, severe corrosion after 10th month.
Stellite 21	75	2.8	66.0	-	43	No evidence of corrosion.
Tantalum	70-75	331	97.5	-	48	No effect on sample, no significant decomposition of hydrazine.

TABLE 50 (CONT)

Materials	Temp. °F	Time Days	N₂H₄ Wt. Percent Before	N₂H₄ Wt. Percent After	Ref.	Remarks
Tantalum	80	30	95.5	93.5	44,48	No apparent effect on sample.
Tin	70-73	365	95.1	-	48	No apparent effect on sample.
Tin	149	333	95.1	-	48	Wt. loss noted by 7th month, specimen turned dark by the 11th month.
Tin	80	30	95.5	92.5	44,48	No apparent effect on sample.
Tin	140	30	95.5	91.5	44,48	No apparent effect on sample.
Solder 90/10	68-77	8.8	93.23	82.32	43	Slight weight loss.
Solder 90/10	80	30	95.5	91.5	44	Short-term service.
Solder 90/10	140	30	95.5	92.5	44	Short-term service.
Silver Solder, Easy Flow	75	7.9	93.23	92.35	43	No apparent effect on material.
Silver Solder, Easy Flow	75	6.9	93.23	86.24	43	No apparent effect on material.
Silver Solder, Easy Flow	250	2.1	96.06	94.22	43	No apparent effect on material.
AM350 Stainless Stl	<160	-	-	-	68	Recommended.
AM355 Stainless Stl	<160	-	-	-	68	Recommended.
17-7 PH Stainless Stl	-	-	-	-	68	Recommended.
17-4 PH Stainless Stl	160	-	-	-	68	Not recommended.
Brass	-	-	-	-	68	Not recommended.
Cadmium	-	-	-	-	68	Not recommended.
Bronze	-	-	-	-	68	Not recommended.
Nickel-Electroless	-	-	-	-	68	Not recommended - some pitting.
Chromium Plating	-	-	-	-	68	Recommended.
Silver	-	-	-	-'	68	Not recommended.
	-	-	-	-	43	
Zinc	-	-	-	-	68	Not recommended.

*Eutectic Hydrazine

TABLE 51

LITERATURE SURVEY

COMPATIBILITY OF VARIOUS PLASTICS AND ELASTOMERS WITH N_2H_4

Material	Temp. °F	Remarks	Ref.
Acadia "O" Ring	-	Unsatisfactory	49
Placticized Kel-F	-	Unsatisfactory	45
Natural Rubber	-	Unsatisfactory	45
Rubber Hose AN-H-35	-	Unsatisfactory	45
Rubber Hose AN-884	-	Unsatisfactory	45
Polyvinyl Chloride	-	Unsatisfactory	48
Rubber Hose, Netco No. 1009 Hyflex	-	Unsatisfactory	45
Saran	-	Unsatisfactory	48
Vermiculite (Insulating asbestos)	-	Unsatisfactory	50
Tefsilon Cable No. 506	-	Unsatisfactory	45
Koroseal	-	Unsatisfactory	43
Polyvinyl Alcohol	-	Unsatisfactory	48
Asbestos (Pyroid & Vellumoid)	ambient	Short-term service	44, 48
Hycar	75	Short-term service	43
Kel-F (unplasticized)	ambient	Short-term service	45
Lithcote	ambient	Short-term service	51
Lucite	ambient	Short-term service	44
Lucoflex	ambient	Short-term service	45
Neoprene	ambient	Short-term service	45
Nukast (Resin bonded graphite)	160 (hydrazine hydrate)	Short-term service	45
Nylon	ambient	Short-term service	37, 48
Plexiglass	ambient	Short-term service	52
Polystyrene	ambient	Short-term service	48
Rubber Hose, AN-H-29	130	Short-term service	45
Silastic 167	ambient	Short-term service	43
Trithene, Type B (Visking Corp.)	ambient	Short-term service	45
Tygon	ambient	Short-term service	45, 48
U.S. Rubber, L7825	ambient	Short-term service	43
U.S. Rubber, M20995	ambient	Short-term service	43
Vinylite (UU 1940)	ambient	Short-term service	45
Wire Insulations	ambient	Short-term service	45
Irvolite (vinyl chloride)	ambient	Short-term service	45
Suprenant Wire B2W2	ambient	Short-term service	45
Neolay (Latex w/nylon coating)	ambient	Short-term service	45
Latex w/thermoplastic coating	ambient	Short-term service	45
Opaque Wire (S9318B-20)	ambient	Short-term service	45
Hydrogenated Polybutadiene Compounds No. 3311, No. 129, No. 3246	ambient	Short-term service	38
Polyethylene	160	Satisfactory	44, 45
Teflon	160	Satisfactory	43, 44

TABLE 51 (CONT)

Material	Temp. °F	Remarks	Ref.
Neoprene	-	Unsatisfactory	68
Mylar	-	Unsatisfactory	68
Viton A	-	Unsatisfactory	68
LS-53	-	Unsatisfactory	68
Buna-N	-	Unsatisfactory	68
Kel-F 5500	-	Unsatisfactory	68
Fluorolube	-	Unsatisfactory	68

TABLE 52

LITERATURE SURVEY –

COMPATIBILITY OF VARIOUS LUBRICANTS WITH N_2H_4

Material	Temp. °F	Remarks	Ref.
D.C. 33	Ambient	Short-term service	53
D.C. 11	Ambient	Short-term service	53
Nordcoseal 147	Ambient	Short-term service	54
Nordcoseal 241	Ambient	Short-term service	40
Silicone Fluid (D.C. 710)	Ambient	Short-term service	43
Varnaton (Varnaton Manufacturing Co.)	-	Acceptable	59
AN-C-58 (Socony-Vacuum)	-	Acceptable	59
Oxyseal (Parker Appliance Company)	-	Acceptable	59
Thread-Tite (Armite Laboratories)	-	Acceptable	59
D.C. 200 Series	-	Acceptable	59
D.C. 550	-	Acceptable	59
D.C. 710	-	Acceptable	59
Graphite	-	Acceptable	68
Sinclair L743 (MIL-L-25336)	-	Acceptable	68
NA2-20502		Acceptable	68

TABLE 53

SUMMARY OF TESTS ACCOMPLISHED UNDER SUBJECT CONTRACT

Material	UDMH at 140°F	N_2H_4 at 140°F	N_2H_4 at 200°F	N_2O_4 at 60 ±5°F
1100 Aluminum		X		
2014 Aluminum	X			X
2024 Aluminum				X
5052 Aluminum	X			
5456 Aluminum	X		X	X
6061 Aluminum		X		
7075 Aluminum	X			X
356 Aluminum				X
AM100A Magnesium	X	X		X
AZ31C Magnesium				X
17-7 PH SS	X	X		X
304 SS		X		X
316 SS	X		X	
321 SS		X		
347 SS		X	X	
416 SS	X		X	X
A110AT Titanium		X		X
C120AV Titanium	X			
Monel	X			X
K-Monel		X	X	
Inconel	X		X	X
A-Nickel		X		X
Haynes Stellite 6K				X
Tantalum	X			X

TABLE 53 (CONT)

Material	UDMH at 75°F	UDMH at 140°F	N₂H₄ at 75°F	N₂H₄ at 140°F	N₂O₄ at 60 ±5°F
Teflon TFE				X	X
Teflon FEP		X		X	X
Polyethylene					X
Silastic LS-53	X		X		X
Garlock Gasket #900		X		X	X
Haveg 61		X		X	
Mylar, Type A		X		X	
Asbestos		X			X
Neoprene				X	
Butyl Compound 805-70		X		X	X
Kel-F 3700		X		X	X
Kel-F 5500		X		X	X
Kel-F 300 (15% glass filled)		X		X	X
Dapon 35		X		X	X
Johns-Manville Service No. 60		X			X
Graphitar #2		X		X	
Graphitar #50		X		X	
DC-33					X
Nordcoseal 147					X
Nordcoseal 421					X
UDMH Lube	X*		X*		
Lox Safe	X*		X*		
ANDOK C	X*		X*		
Carum 200	X*		X*		
Carum 325	X*		X*		
S-#58-M	X*		X*		
Fluorolube HG			X		X
Molykote G					X
Delanium		X		X	X
Viton A - O-ring -G227-19 274-90					X
Viton A - O-ring -G227-19 270-70					X

TABLE 53 (CONT)

Material	UDMH		N_2H_4		N_2O_4 at
	at 75°F	at 140°F	at 75°F	at 140°F	60 ±5°F
Irradiated Neoprene					X
Stillman Rubber Compound + H1057 O-ring					X
Silicone Rubber with Unplasticized Kel-F Cover - O-ring					X
Genetron XE-2B					X
Genetron GCX-3B		X			X
Raythene N	X (110°F)				X
Genetron HL Plastic	X				
Epon 815	X				

*Dynamic tests with lubricant tester.

TABLE 54

COMPATIBILITY OF METALS WITH N_2O_4 AT 60 ±5° F

Metal	Spec. No.	Length of Test	Area of Spec.	Weight gms Initial	Final	Corrosion mpy	% Wt. Change	Remarks
2024 Al	A-13	30 days	3.58	4.6071	4.6071	0.000	0.000	No change in appearance
2024 Al	A-14	30 days	3.58	4.6236	4.6236	0.000	0.000	
2024 Al	A-15	30 days	3.57	4.6069	4.6069	0.000	0.000	
2024 Al	A-13	63 days	3.58	4.6071	4.6067	0.014	-0.009	Slight, uneven discoloration on specimens
2024 Al	A-14	63 days	3.58	4.6236	4.6232	0.014	-0.009	
2024 Al	A-15	63 days	3.57	4.6069	4.6066	0.011	-0.007	
7075 Al	V-13	36 days	4.00	9.2049	9.2048	0.007	-0.001	Minor discoloration in vapor phase
7075 Al	V-14	30 days	4.00	9.2126	9.2126	0.000	0.000	
7075 Al	V-15	30 days	4.05	9.3446	9.3446	0.000	0.000	
AM 100A Mg	X-7	30 days	5.65	16.7542	16.7603	--	0.036	Slight grey discoloration on specimens
AM 100A Mg	X-8	30 days	5.67	16.8897	16.8933	--	0.021	
AM 100A Mg	X-9	30 days	5.67	16.8854	16.8893	--	0.023	
AZ31C Mg	C-13	30 days	3.40	2.2632	2.2626	0.089	-0.027	Slight discoloration on specimens
AZ31C Mg	C-14	30 days	3.51	2.6041	2.6035	0.077	-0.023	
AZ31C Mg	C-15	30 days	3.48	2.4981	2.4975	0.080	-0.024	
AZ31C Mg	C-13	63 days	3.40	2.2632	2.2623	0.063	-0.040	Uneven milky discoloration, some pitting
AZ31C Mg	C-14	63 days	3.51	2.6041	2.6029	0.073	-0.046	
AZ31C Mg	C-15	63 days	3.48	2.4981	2.4970	0.070	-0.044	
17-7 PH SS	G-13	30 days	3.56	11.7532	11.7527	0.014	-0.004	Minor discoloration in vapor phase
17-7 PH SS	G-14	30 days	3.56	11.8317	11.8312	0.014	-0.004	
17-7 PH SS	G-15	30 days	3.56	11.8191	11.8188	0.008	-0.003	
304 SS	D-13	30 days	3.56	12.4416	12.4414	0.005	-0.002	Minor discoloration in vapor phase
304 SS	D-14	30 days	3.56	12.4169	12.4168	0.003	-0.001	
304 SS	D-15	30 days	3.57	12.5982	12.5979	0.008	-0.002	
304 SS	D-13	63 days	3.56	12.4416	12.4412	0.005	-0.003	Slight, even etch
304 SS	D-14	63 days	3.56	12.4169	12.4166	0.004	-0.002	
304 SS	D-15	63 days	3.57	12.5982	12.5978	0.005	-0.003	
Monel	M-13	30 days	3.56	13.2730	13.2725	0.012	-0.004	Slight discoloration in liquid phase
Monel	M-14	30 days	3.71	13.7091	13.7086	0.012	-0.004	
Monel	M-15	30 days	3.57	13.2555	13.2547	0.020	-0.006	

TABLE 54 (CONT)

Metal	Spec. No.	Length of Test	Area of Spec.	Weight gms Initial	Weight gms Final	Corrosion mpy	% Wt. Change	Remarks
Monel	M-13	63 days	3.56	13.2730	13.2716	0.016	-0.011	Uneven, gray discoloration on specimens
Monel	M-14	63 days	3.71	13.7091	13.7067	0.027	-0.018	
Monel	M-15	63 days	3.57	13.2555	13.2531	0.028	-0.018	
416 SS	Z-13	30 days	3.25	19.7744	19.7736	0.024	-0.004	Complete immersion, no change in appearance
416 SS	Z-14	30 days	3.25	19.6129	19.6122	0.021	-0.004	
356 Al	U-13	33 days	3.78	14.6178	14.6172	0.040	-0.004	Slight, mottled discoloration on specimens
356 Al	U-14	33 days	3.77	14.5498	14.5492	0.040	-0.004	
356 Al	U-15	33 days	3.79	14.5973	14.5966	0.047	-0.005	
Inconel	J-13	33 days	3.52	12.4878	12.4880	--	0.002	Slight, even etch
Inconel	J-14	33 days	3.45	12.0845	12.0846	--	0.001	
Inconel	J-15	33 days	3.49	12.2082	12.2083	--	0.001	
2014 Al	Q-13	63 days	3.59	4.9100	4.9095	0.018	-0.010	Minor discoloration in vapor phase
2014 Al	Q-14	63 days	3.59	4.9180	4.9173	0.025	-0.014	
2014 Al	Q-15	63 days	3.53	4.8100	4.8093	0.025	-0.015	
5456 Al	R-13	63 days	3.66	4.9248	4.9243	0.019	-0.010	Slight discoloration at liquid/vapor interface
5456 Al	R-14	63 days	3.66	4.9299	4.9295	0.015	-0.008	
5456 Al	R-15	63 days	3.66	4.9493	4.9489	0.015	-0.008	
Haynes Stellite 6K	ST-4	63 days	4.74	14.8223	14.8209	0.013	-0.009	No change in appearance
A-Nickel	P-13	30 days	3.48	11.0165	11.0162	0.008	-0.003	Slight discoloration at liquid/vapor interface
A-Nickel	P-14	30 days	3.49	11.0532	11.0528	0.010	-0.004	
A-Nickel	P-15	30 days	3.50	10.9302	10.9298	0.010	-0.004	
A-Nickel	P-13	63 days	3.48	11.0165	11.0155	0.012	-0.009	Slight brown discoloration on specimens
A-Nickel	P-14	63 days	3.49	11.0532	11.0521	0.013	-0.010	
A-Nickel	P-15	63 days	3.50	10.9302	10.9291	0.013	-0.010	
Tantalum	S-13	30 days	3.57	25.7277	25.7275	0.003	-0.001	No change in appearance
Tantalum	S-14	30 days	3.60	26.0636	26.0635	0.001	0.000	
Tantalum	S-15	30 days	3.57	25.7033	25.7032	0.001	0.000	
A 110 AT Ti	H-13	7 days	3.54	7.1296	7.1296	0.000	0.000	No change in appearance - test terminated after one week
A 110 AT Ti	H-14	7 days	3.55	7.1037	7.1037	0.000	0.000	
A 110 AT Ti	H-15	7 days	3.51	7.0165	7.0164	0.021	-0.001	

TABLE 55

COMPATIBILITY OF NONMETALLIC MATERIALS WITH N_2O_4 AT 60 ±5°F

Material	Initial Volume in 3×10^3	% Vol Change Before Outgassing	% Vol Change After Outgassing	Initial Wt. Grams	% Wt. Change After Outgassing	Exposure Time	Remarks*
ELASTOMERS							
Kel-F 3700 O-Ring	---	+300 (est)	---	---	---	45 min	25-50% swelling**; **physical properties and appearance good
Kel-F 5500 O-Ring	---	+450 (est)	---	---	---	45 min	50-75% swelling**; **physical properties poor; surface pimpled
Butyl Rubber Compound 805-70 O-Ring	---	---	---	---	---	2 hours	Softened, lost elastic properties
Butyl Rubber Compound 805-70 O-Rings	40.50 / 5.64 / 5.64	--- / --- / ---	.31 / +18 / +18	0.8804 / 0.1309 / 0.1310	-10 / +9.0 / +8.6	7 days / 7 days / 7 days	Plastic and tacky, lost elastic properties, N_2O_4 clear
Viton A (G227-19) O-Ring (274-90)	43.37	+120	+15	1.6391	+13	1 day	Physical properties and appearance good
Viton A (G227-19) O-Ring (270-70)	43.37	+238	+34	1.5962	+30	1 day	Physical properties and appearance good
Irradiated Neoprene	---	---	---	2.5289	+39	6 days	Swollen, sticky; **became hard and brittle after outgassing 24 hours, N_2O_4 darkened
Stillmen Rubber Compound TH 1057 O-Ring	42.17 / 43.37	+111 / +205	+2.9 / -18	1.2944 / 1.2495	-2.7 / -13	1 day / 31 days	Physical properties and appearance good; N_2O_4 unchanged
Silastic LS-53	75.36 / 73.91	+54 / +285	-2 / -22	1.5908 / 1.5475	-2.2 / -8.4	1 day / 31 days	Physical properties and appearance good; N_2O_4 unchanged
Silicone Rubber with unplasticized Kel-F cover, O-Ring	306.85	Nil	Nil	8.6864	-26	63 days	Appeared unaffected, but rubber core turned to a white powder after outgassing; N_2O_4 unchanged
PLASTICS							
Teflon FEP	12.10 / 12.81 / 13.53	Nil / Nil / Nil	Nil / Nil / Nil	0.4292 / 0.4518 / 0.4585	+ 0.07 / + 0.11 / + 0.07	24 days / 24 days / 24 days	Physical properties and appearance excellent; N_2O_4 unchanged
Teflon TFE V-Rings	18.89 / 19.61 / 19.13	Nil / Nil / Nil	Nil / Nil / Nil	0.6734 / 0.6954 / 0.6804	+ 0.09 / + 0.04 / + 0.04	30 days / 30 days / 30 days	Physical properties and appearance excellent; N_2O_4 unchanged
Genetron XE-2B Clear / Cloudy	26.25 / 26.25	Nil / Nil	Nil / Nil	0.8678 / 0.9387	+ 4.6 / + 2.5	32 days / 32 days	Physical properties and appearance excellent; N_2O_4 unchanged

TABLE 55 (CONT)

Material	Initial Volume in 3×10^3	% Vol Change Before Outgassing	% Vol Change After Outgassing	Initial Wt. Grams	% Wt. Change After Outgassing	Exposure Time	Remarks*
Genetron Clear GCX-3B Cloudy	26.25 26.25	Nil Nil	Nil Nil	0.9174 0.9507	+ 4.6 + 1.8	32 days 32 days	Physical properties and appearance excellent; N_2O_4 unchanged
Raythene-N (Irradiated Polyolefin)	17.79	Nil	Nil	0.4613	- 7.2	63 days	Excellent appearance but cracked when flexed; N_2O_4 unchanged
ASBESTOS FILLED GASKET MATERIAL							
Johns Manville Service No. 60	145.69 142.74 142.74	--- ---	.61 .61 .61	4.1100 4.1315 3.9826	.55 .55 .53	7 days 7 days 7 days	White and yellow crystalline salts on surfaces after outgassing. Swelled in thickness only. Darkened N_2O_4 considerably
Garlock No. 900	85.37 85.37 91.06	Nil Nil Nil	Nil Nil Nil	2.3054 2.3609 2.5176	.38 .45 .32	63 days 63 days 63 days	Laminar type blistering on both surfaces. Considerably softened before N_2O_4 outgassed N_2O_4 clear.
GRAPHITE MATERIAL							
Delanium (with plastic binder) (1)	250.61	Nil	Nil	7.0069	+ 7.5	30 days	Physical properties and appearance excellent; N_2O_4 unchanged
Graphitar No. 2	184.57	Nil	Nil	5.9962	+ 7.4	30 days	Physical properties and appearance excellent; N_2O_4 unchanged
Graphitar No. 50	307.06	Nil	Nil	8.5197	+ 9.4	30 days	Physical properties and appearance excellent; N_2O_4 unchanged
LUBRICANTS							
Fluorolube HG Grease	---	---	---	1.5707	---	3 days	Grease disappeared, but film left on container surfaces; N_2O_4 clear
Dow Corning No. 33 Grease	---	---	---	0.2253	---	3 days	Grease disappeared completely; N_2O_4 clear
Nordcoseal 421 Grease	---	---	---	0.8303	-54	30 days	Hard, brittle, after outgassing; N_2O_4 darkened somewhat
Molycote G (MoS_2) (Grease-Suspension)	---	---	---	1.0447	-39	30 days	Retains lubricity, but grease component apparently lost; N_2O_4 cloudy
Nordcoseal 147 Grease	---	---	---	0.2355	- 8.3	63 days	Grease hard thin film after outgassing; N_2O_4 clear

* Except where noted, the Remarks refer to conditions after outgassing.
"Physical properties" in this table means apparent physical properties (not measured)
** "By swelling" is meant linear change in dimensions.
*** Before outgassing.
(1) Delanium Company out of business.

TABLE 56

COMPATIBILITY OF METALS WITH UDMH AT 140°F FOR ONE MONTH

Metal	Spec. No.	Area of Spec. Sq. In.	Weight, gms. Initial	Weight, gms. Final	% Wt. Change	Fuel Analysis Color	% Conc.	Sp. Gr. 77/39°F	Remarks
UDMH (Blank No. 1: Initial 98.2%, Sp. Gr. 0.7844)						Red	70.9	0.8923	Decomposition - from breathing
7075 Al.	V-4	4.01	9.3057	9.3077	0.021	Yellow	77.3	0.8613	Grey discoloration in liquid phase and on edges of specimens
7075 Al.	V-5	4.01	9.3573	9.3608	0.037				
7075 Al.	V-6	3.99	9.2264	9.2293	0.031				
7075 Al. **	V-1	3.98	9.1601	9.1601	0.000	Straw Yellow	94.6	0.8005	No change in appearance of specimens
7075 Al. **	V-2	3.94	9.3370	9.3366	-0.004				
7075 Al. **	V-3	3.94	9.3533	9.3529	-0.004				
AM 100A Mg. *	X-4	5.60	16.8529	16.8566	0.022	Red	81.8	0.8502	Minor discoloration at liquid/vapor interface and in vapor phase
AM 100A Mg. *	X-5	5.60	16.7159	16.7228	0.041				
AM 100A Mg. *	X-6	5.60	16.8732	16.8733	0.001				
17-7 PH SS	G-1	3.43	11.8274	11.8274	0.000	Orange	86.1	0.8298	No change in appearance
17-7 PH SS	G-2	3.43	11.8795	11.8792	-0.003				
17-7 PH SS	G-3	3.52	11.9092	11.9090	-0.002				
C 120 AV Ti *	K-1	3.52	6.9996	6.9990	-0.009	Orange	53.5	0.9420	Spotted black discoloration in vapor phase
C 120 AV Ti *	K-2	.2	6.9684	6.9680	-0.006				
C 120 AV Ti *	K-3	3.52	6.9774	6.9770	-0.006				
C 120 AV Ti **	K-4	3.50	7.0037	7.0039	0.003	Straw Yellow	95.5	0.7976	Minor discoloration in vapor phase
C 120 AV Ti **	K-5	3.50	6.9963	6.9967	0.006				
C 120 AV Ti **	K-6	3.41	6.9906	6.9910	0.006				
Monel	M-1	3.52	13.6085	13.6085	0.000	Red-Orange	53.8	0.9319	Minor discoloration at liquid/vapor interface
Monel	M-2	3.53	13.4932	13.4928	-0.003				
Monel	M-3	3.53	13.4390	13.4387	-0.002				
Tantalum	S-1	3.52	25.1283	25.1281	-0.001	Red	81.4	0.8485	No change in appearance
Tantalum	S-2	3.52	26.0453	26.0452	0.000				
Tantalum	S-3	3.52	25.6749	25.6744	-0.002				

TABLE 56 (CONT)

UDMH (Blank No. 2: Initial 96.0% Sp. Gr. 0.7849)

Metal	Spec. No.	Area of Spec. Sq. In.	Weight, gms. Initial	Final	% Wt. Change	Fuel Analysis Color	% Conc.	Sp. Gr. 77/39°F	Remarks
						Straw Yellow	95.9	0.7844	
2014 Al.	Q-1	3.49	4.7785	4.7787	0.004	Straw Yellow	93.9	0.8037	No significant change in appearance
2014 Al.	Q-2	3.59	4.9074	4.9074	0.000				
2014 Al.	Q-3	3.49	4.9464	4.9464	0.000				
5052 Al.	L-1	3.29	2.7064	2.7062	-0.007	Straw Yellow	94.5	0.7981	Minor discoloration at liquid/vapor interface
5052 Al.	L-2	3.29	2.7516	2.7514	-0.007				
5052 Al.	L-3	3.29	2.7502	2.7500	-0.007				
5456 Al.	RR-1	3.61	4.9003	4.9003	0.000	Straw Yellow	95.5	0.7947	No change in appearance of specimens
5456 Al.	RR-2	3.61	4.9205	4.9206	0.002				
5456 Al.	RR-3	3.61	4.9067	4.9068	0.002				
316 SS	Y-1	3.25	11.5815	11.5816	0.001	Straw Yellow	95.8	0.8002	Minor discoloration in vapor phase near liquid/vapor interface
316 SS	Y-2	3.15	11.0239	11.0238	-0.001				
316 SS	Y-3	3.25	11.2639	11.2640	0.001				
Inconel	J-1	3.40	12.3410	12.3409	-0.001	Straw Yellow	92.2	0.8045	No change in appearance of specimens
Inconel	J-2	3.40	12.3977	12.3978	0.001				
Inconel	J-3	3.40	12.5500	12.5500	0.000				
416 SS	Z-1	3.26	20.0870	20.0872	0.001	Straw Yellow	95.0	0.8018	Specimens completely submerged; no change in appearance
416 SS	Z-2	3.25	19.6451	19.6453	0.001				

NOTE: Aluminum tested in highest temper available
Stainless Steels tested in annealed condition

* An additional 94 days at 115°F showed no further significant change

** Repeat tests (see text)

TABLE 57

COMPATIBILITY OF METALS WITH N_2H_4 AT 140°F FOR ONE MONTH

Metal	Spec. No.	Area of Spec. Sq. In.	Weight, gms. Initial	Final	% Wt. Change	Fuel Analysis % Conc.	Sp. Gr. 77/39°F	Remarks
Hydrazine (Blank No. 1: Initial 95.5% Sp.Gr. 1.004 ± .002-MIL-P-26536A)						59.57	1.0262	Breathing air during test
1100 Al.	T-7	3.99	8.9870	8.9890	0.022			
1100 Al.	T-8	3.99	9.0421	9.0440	0.021	80.04	1.0214	Discolored at liquid/vapor interface; minor etch in liquid phase
1100 Al.	T-9	3.99	9.0318	9.0332	0.015			
6061 Al.	B-7	3.35	4.0824	4.0824	0.000			
6061 Al.	B-8	3.26	3.9785	3.9784	-0.003	91.25	1.0146	Slight discoloration at liquid/vapor interface and in vapor phase
6061 Al.	B-9	3.45	4.2197	4.2195	-0.005			
AM 100A Mg.	X-10	5.60	16.5044	16.5224	0.110			
AM 100A Mg.	X-11	5.60	16.5794	16.6937	0.086	88.21	1.0164	Precipitate in fuel; specimens badly corroded; X-12 badly pitted
AM 100A Mg.	X-12	5.60	16.6684	16.6295	-0.234			
17-7 PH SS	G-7	3.52	11.9063	11.9064	0.001			
17-7 PH SS	G-8	3.52	11.5467	11.9468	0.001	90.83	1.0196	Minor discoloration at liquid/vapor interface
17-7 PH SS	G-9	3.52	11.8838	11.8838	0.000			
304 SS	D-7	3.53	12.4094	12.4096	0.002			
304 SS	D-8	3.53	12.5931	12.5933	0.002	82.41	1.0140	Minor discoloration at liquid/vapor interface
304 SS	D-9	3.53	12.6165	12.6166	0.001			
321 SS	E-7	3.53	12.0978	12.0976	-0.002			
321 SS	E-8	3.53	11.9626	11.9625	-0.001	89.69	1.0243	Minor discoloration at liquid/vapor interface
321 SS	E-9	3.53	11.7154	11.7154	0.000			
347 SS	F-7	3.53	12.5906	12.5898	-0.006			
347 SS	F-8	3.53	12.5525	12.5523	-0.002	77.78	1.0243	Minor discoloration at liquid/vapor interface
347 SS	F-9	3.53	12.4540	12.4535	-0.004			

TABLE 57 (CONT)

Metal	Spec. No.	Area of Spec. Sq. In.	Weight, grms. Initial	Final	% Wt. Change	Fuel Analysis % Conc.	Sp. Gr. 77/39°F	Remarks
A 110 AT Ti	H-7	3.54	7.1349	7.1346	-0.004			Minor discoloration at
A 110 AT Ti	H-8	3.45	7.1859	7.1858	-0.001	88.06	1.0148	liquid/vapor interface
A 110 AT Ti	H-9	3.45	7.2663	7.2663	0.000			slight bronzing in vapor phase
K-Monel	N-7	3.44	12.7938	12.7942	0.003			Copper color and salt
K-Monel	N-8	3.52	13.2759	13.2766	0.005	88.86	1.0139	formation at liquid/vapor interface, slight bronzing
K-Monel	N-9	3.52	13.3626	13.3624	-0.001			in liquid phase
Nickel	P-7	3.36	11.3521	11.3520	-0.001			Slight etching and salt
Nickel	P-8	3.36	11.4217	11.4218	0.001	38.31	1.0147	build-up at liquid/vapor interface; slight salt
Nickel	P-9	3.36	11.2486	11.2488	0.002			build-up in liquid phase

REPEAT TESTS

Hydrazine (Blank No. 2: Initial 96.6% Sp. Gr. 1.0032)

Metal	Spec. No.	Area of Spec. Sq. In.	Weight, grms. Initial	Final	% Wt. Change	Fuel Analysis % Conc.	Sp. Gr. 77/39°F	Remarks
1100 Al.**	T-10	3.98	9.0969	9.0968	-0.001	97.1	1.0063	
1100 Al.**	T-11	3.88	8.9843	8.9841	-0.002	93.6	1.0096	Minor stain in vapor phase
1100 Al.**	T-12	3.98	9.0984	9.0983	-0.001			
304 SS**	D-10	3.53	12.6931	12.6931	0.000			Minor spotted discoloration
304 SS**	D-11	3.43	12.4527	12.4525	-0.002	97.9	1.0068	in vapor phase
304 SS**	D-12	3.62	13.0624	13.0625	0.001			
A 110 AT Ti**	H-1	3.46	7.1208	7.1208	0.000			
A 110 AT Ti**	H-10	3.43	6.6344	6.6343	-0.002	96.6	1.0062	No change in appearance
A 110 AT Ti**	H-12	3.43	6.9711	6.9709	-0.003			

NOTE: Aluminum tested in highest temper available
Stainless Steels tested in annealed condition

TABLE 58

COMPATIBILITY OF METALS WITH N_2H_4 AT 200°F FOR ONE MONTH

Metal	Specimen No. S	Area in²	Weight Gms. Initial	Final	% Wt. Change	Fuel Analysis % Conc.	Sp. Gr. 77°/39°F	Remarks
Hydrazine (Blank Initial 96.6% Sp. Gr. 1.0032)						94.6	1.0098	
5456 Al.	RR-7	3.61	4.9051	4.9051	0.000			
5456 Al.	RR-8	3.61	4.9103	4.9100	-0.006	95.1	1.0087	Slight discoloration with salt build-up at liquid-vapor interface.
5456 Al.	RR-9	3.61	4.8984	4.8985	+0.002			
316 SS	Y-7	3.25	11.1753	11.1749	-0.003			
316 SS	Y-8	3.25	11.3599	11.3594	-0.004	92.9	1.0102	Bronzing and/or rust in vapor phase and at liquid-vapor interface.
316 SS	Y-9	3.25	11.2467	11.2461	-0.005			
347 SS	F-10	3.54	12.4768	12.4766	-0.002			
347 SS	F-11	3.44	12.4608	12.4602	-0.005	92.7	1.0120	Black discoloration in vapor phase, and at liquid-vapor interface.
347 SS	F-12	3.52	12.2024	12.2019	-0.004			
Inconel	J-7	3.39	12.0440	12.0437	-0.002			
Inconel	J-8	3.40	12.5520	12.5522	+0.002	93.6	1.0105	Brown discoloration in vapor phase; red salt build-up at liquid-vapor interface.
Inconel	J-9	3.39	12.3970	12.3974	+0.003			
416 SS	Z-7	3.25	19.8792	19.8794	+0.001	95.1	1.0075	Discolored in vapor phase; pitting corrosion at liquid-vapor interface.
416 SS	Z-8	3.25	19.8860	19.8860	0.000			
K-Monel	N-10	3.45	13.3268	13.3201	-0.050			
K-Monel	N-11	3.43	13.2208	13.2200	-0.006	92.4	1.0118	Badly corroded in vapor phase; blue salts at liquid-vapor interface; analysis showed nickel and hydrazine.
K-Monel	N-12	3.51	13.5466	13.5458	-0.006			

NOTE: Aluminum tested in highest temper available
Stainless Steels tested in annealed condition.

TABLE 59

COMPATIBILITY OF PLASTICS AND ELASTOMERS WITH UDMH AT 140 F FOR ONE MONTH

Material	Specimen Area In²	Specimen Vol In³	% Vol Change	Weight, gms Initial	Weight, gms Final	% Wt. Change	Fuel Analysis Color	Fuel Analysis % Conc.	Fuel Analysis Sp. Gr. 77 /39 F	Remarks
UDMH Blank (Initial 96.0%, Sp. Gr. 0.7849)							Straw	95.9	0.7973	
Johns-Manville Service #60	3.54	0.139	2.5	4.1349	4.0895	-1.1	Straw	95.0	0.8046	White ppt. in fuel; no significant change in specimen
Haveg 61	8.01	0.43	56.0	13.7723	15.3640	+11.6	Brown	92.6	0.8062	Specimen lighter in color
Dapon 35	3.91	0.304	8.9	6.7668	7.0558	+4.3	Yellow	93.6	0.8056	White ppt. in fuel; slight embrittlement on sharp edges of specimen
Kel-F 300 (15% glass filled)	3.80	0.183	0.0	6.6734	6.7341	+0.9	Orange	85.4	0.8410	Specimens darker in color
Silastic LS-53	--	0.055		1.1955	--	--	--	--	--	Tested at ambient temperature. Specimen dissolved within 18 hours.
Butyl O-Ring Compound 805-70	0.73 0.73	0.26 0.26	5.0 3.9	0.5235 0.5270	0.5502 0.5550	+5.1 +5.3	Orange slight ppt.	94.4	0.8029	Apparent Modulus of Rigidity, psi*. Initial, 336, 340; Final, 81, 92.
Kel-F 5500* Base Elastomer "O" Ring Kel-F 3700* Base Elastomer "O" Ring										Dissolved within 18 hours. Gross swelling and deterioration within 18 hours.
Teflon FEP	3.08	0.016	0.0	0.5701	0.5711	+0.17	Straw	93.1	0.8042	No change in specimen
Garlock Gasket #900	3.46	0.10	0.0	2.6569	2.6834	+1.0	Orange	91.8	0.8131	White ppt. in fuel; specimens lighter in color showed a 0.36% weight gain after 48 hours.
Graphitar #2	4.17	0.31	0.0	9.8163	9.9348	+1.2	Yellow	91.7	0.8084	No change in specimen; 0.62% weight gain after 48 hours.
Graphitar #50	4.01	0.33	0.0	9.4981	9.8860	+4.1	Yellow	91.0	0.8121	Black colloidal ppt. in fuel; no change in specimen; 2.4% weight gain after 48 hours.
Delanium (graphite with plastic binder)	2.98	0.20	0.0	6.1626	6.2672	+1.7	Yellow	91.9	0.8072	No change in specimen, 0.09% weight gain after 48 hours.
Mylar, Type A	4.17	0.023	--	0.4765	--	--	Yellow	--	--	Specimen completely deteriorated.

* Determined on Gehman Stiffness Tester per ASTM D1053-58T

TABLE 60

COMPATIBILITY OF PLASTICS AND ELASTOMERS WITH N_2H_4 FOR ONE MONTH AT 140°F

Material	Specimen Area in²	Vol in³	% Vol Change	Weight Gms. Initial	Final	% Wt. Change	Fuel Analysis % Conc.	Sp. Gr. 77°/39°F	Remarks
Hydrazine (Blank: Initial 96.6% Sp. ∴ 1.0032)							94.6	1.0098	
Dapon 35	3.60	0.28	-	6.8275	-	-			Specimen dissolved within one week.
LS-53 Silastic	-	0.052	+10	1.1929	1.4040	+17.7	95.2	1.0083	Tested at ambient temperature. Specimen intact, but badly deteriorated.
Butyl O-Ring Compound 805-70	0.73	0.026	+9	0.5286	0.5495	+4	96.4	1.0062	Apparent Modulus of Rigidity, psi* Initial, 326, 324; Final, 150, 164.
	0.73	0.026	+9	0.5190	0.5395	+4	-	-	
Kel-F 5500 Base O-Rings* Kel-F 3700 Base O-Rings*									Gross swelling within 18 hours. Specimens completely deteriorated.
Teflon 100 (FEP)	3.08	0.017	-	0.5705	0.5709	+.07	94.9	1.0071	No change in specimen.
Garlock Gasket #900	3.4?	0.095	-	2.6024	2.7622	+6.1	96.5	1.0072	Specimen lighter in color. Absorbed fuel released when out of test.
Graphitar #2	?.??	0.28	-	8.6704	8.9335	+3.0	95.6	1.0021	No change in specimen.
Kel-F 300 (15% glass filled)		0.18	-	6.8298	-	-	-	-	Specimen dark in color; badly deteriorated; swollen in liquid phase
Delanium	3.11	0.21	-	6.1796	6.4019	+3.6	96.0	1.0074	No change in specimens.
	4.11	0.022	-	0.4700	-	-	-	-	Specimen dissolved within 24 hours.
?eopl ??	?.??	0.018	+83	0.5297	0.6171	+16.5	95.4	1.0053	Apparent Modulus of Rigidity, psi*. Initial 144; Final 29.
Haveg 61**	7.96	0.41	+37	13.2384	14.6105	+10	35.0	1.0098	Specimens lighter in color.
Graphitar ?50**	3.24	0.26	-	8.1702	8.4463	+3.4	94.2	1.0095	No change in specimen.

*Determined on Gehman Stiffness Tester per ASTM D1053-58T
**Tests run at 200°F

TABLE 61

LUBRICANT TEST DATA

Lubricant	Source of Lubricant	Condition of O-Rings at End of Test		Force (lbs) Following 24 Hr. Shutdown	
		Piston O-Ring	Shaft O-Ring	Initial	Final
UDMH TESTS:					
UDMH Lube*	Bell Aerosystems Co.	Good	Fair	54	21
S-#58-M	N.Y. & N.J. Lubricating Co.	Good	Good	40	27
LOX-Safe	Redel Inc., Anaheim, Calif.	Good	Good	43	14
ANDOK C	Esso Standard Oil Co.	Good	Fair (rolled)	39	25
Carum 200	Esso Standard Oil Co.	Abraded, sticky	Abraded, sticky, rolled	60	30
Carum 325	Esso Standard Oil Co.	Fair	Fair (rolled)	52	39
N_2H_4 TESTS:					
UDMH Lube	Bell Aerosystems Co.	Good	Good	4	4
S-#58-M	N.Y. & N.J. Lubricating Co.	Good	Good	13	13
LOX-Safe	Redel Inc., Anaheim, Calif.	Good	Good	28	11
ANDOK C	Esso Standard Oil Co.	Good	Good	14	9
Carum 200	Esso Standard Oil Co.	Good, but slightly sticky		30	10
UDM-M Lube	Superlube Inc. Cleveland, Ohio	Fair	Fair	42	8

*UDMH Lube = UDM Lube – Superlube Inc./Electro Mechanics No. 20057 (50-50 mixture)

TABLE 62

SUMMARY OF COMPATIBILITY DATA FOR MATERIALS OF CONSTRUCTION
WITH THE ANHYDROUS* PROPELLANTS UDMH, N_2H_4, AND N_2O_4 – SATISFACTORY FOR USE

The following materials are satisfactory for use with these propellants under the test conditions described in this report:

UDMH at 140°F	Hydrazine at 140°F	N_2O_4 at 60 ±5°F
7075 Aluminum	6061 Aluminum 1100 Aluminum	2014 Aluminum
2014 Aluminum	17-7 PH Stainless Steel	2024 Aluminum
5052 Aluminum	321 Stainless Steel	7075 Aluminum
5456 Aluminum	347 Stainless Steel	5456 Aluminum
316 Stainless Steel	A 110 AT Titanium	356 Aluminum
17-7 PH Stainless Steel	Butyl Rubber Compound, 805-70	17-7 PH Stainless Steel PH 15-7 Mo Stainless Steel
416 Stainless Steel	Graphitar #2	304 Stainless Steel
C 120 AV Titanium	Graphitar #50 at 200°F	416 Stainless Steel
Monel	Delanium	Monel
Tantalum	Teflon FEP	Inconel
Inconel	UDMH Lubricant, at room temperature	Tantalum
Butyl Rubber Compound, 805-70	S-#58-M Non-Fluid Oil at room temperature	Haynes Stellite 6K
Teflon FEP	Lox Safe, at room temperature	"A" Nickel
Teflon TFE		Teflon FEP
Graphitar #2		Teflon TFE
Delanium (graphite w/plastic binder)		Genetron XE-2B
UDMH Lubricant at room temp.		Genetron GCX-3B
Lox Safe at room temperature		Graphitar #2
S-#58-M Non-Fluid, Oil at room temperature		Graphitar #50 Graphitar #39 Delanium Molykote G (MoS_2)

*The presence of moisture may adversely affect the corrosion resistance of these materials.

TABLE 63

SUMMARY OF COMPATIBILITY DATA FOR MATERIALS OF CONSTRUCTION WITH THE ANHYDROUS* PROPELLANTS UDMH, N_2H_4, AND N_2O_4 – SATISFACTORY FOR SHORT-TERM SERVICE

The following materials are satisfactory for short term service** with the propellants but should be tested further to determine specific use limits:

UDMH at 140°F	N_2H_4 at 140°F	N_2O_4 at 60 ±5°F
Johns-Manville Svc. #60		AM 100A Magnesium
Dapon 35	5456 Aluminum at 200°F	AZ31C Magnesium
Kel-F 300 (15% glass filled)	347 Stainless Steel 316 Stainless Steel at 200°F Garlock Gasket #900 at 200°F	Stillman Rubber Compound TH 1057
Garlock Gasket #900	Haveg 61, at 200°F	Silastic LS-53
Graphitar #50	ANDOK C, at room temperature	Silicone Rubber O-Ring with unplasticized Kel-F cover
Haveg 61	UDM Lube, at room temperature	
Raythene N	Carum 200, at room temperature	Raythene N
Genetron HL	Neoprene	Viton A "O" Ring
ANDOK C, at room temperature		Fluorolube HG
Carum 200 at room temperature		NORDCOSEAL #147
		NORDCOSEAL #421

*The presence of moisture may adversely affect the corrosion resistance of these materials.

**The materials are affected in such a way that for certain applications they may be used. For example, Raythene N, an irradiated polyolefin may be used successfully as insulation for electrical wires when the Raythene N is exposed to N_2O_4 vapors intermittently.

TABLE 64

SUMMARY OF COMPATIBILITY DATA FOR MATERIALS OF CONSTRUCTION
WITH THE ANHYDROUS PROPELLANTS UDMH, N_2H_4, AND N_2O_4 – UNSATISFACTORY

The following materials are unsatisfactory for use with these propellants**.

UDMH at 140°F	Hydrazine at 140°F	N_2O_4 at 60 ±5°F
Silastic LS-53 at room temperature	AM 100A Magnesium	A 110 AT Titanium*
Kel-E-1 (Kel-F 3500 Base "O" Ring)	K-Monel at 200°F	Kel-F 3700
Kel-E-5 (Kel-F 3700 Base "O" Ring)	"A" Nickel	Kel-F 5500
Mylar, Type A	Inconel, at 200°F	Butyl Rubber Compound 805-70
Genetron, GCX-3B	416 Stainless Steel at 200°F	
Epon 815	Dapon 35	Irradiated Neoprene
Carum 325 at room temperature	Silastic LS-53 at room temp.	Johns-Manville, Svc. #60
	Kel-E-1	Garlock #900
	Kel-E-5	DC 33 Grease
	Kel-F-300 (15% glass filled)	
	Mylar, Type A	

*Not seriously .ffected but potentially dangerous since impact sensitive deposits have been known to form on titanium in the presence of strong oxidizers.

**Although these materials are unsatisfactory for general service with these propellants. they do not create a hypergolic or an explosive condition with these propellants. Despite the fact that these materials generally deteriorate rapidly in the liquid propellant, some may afford a first order protection as indicated in the test results in the body of this report.

TABLE 65

FLOW ANALYSIS – 62-672-183 THRUST CHAMBER PROPELLANT VALVE (FUEL AND OXIDIZER)

(FUEL)

Room Temp. Accept. Test At Rated Flow to Establish Flow vs Δp Test Liquid – Methanol Sp. Gr. 0.794

Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi
430	2.72	26.8
548	3.06	33.6
665	3.36	39.5
787	3.64	47.5
890	3.87	53.9

Initial Room Temp. Test Ambient & Valve Temp. 70±5°F Test Liquid UDMH Sp.Gr. 0.799 Temp. of UDMH 61°F

Tank Press. psig	Equiv. Water Flow Lbs/sec	Δp psi
417	2.74	27.2
521	3.04	33.5
629	3.33	40.5
739	3.59	47.2
798	3.73	51.1

Elevated Temperature Test: Not Conducted See Conclusions

Final Room Temperature Test: Not Conducted See Conclusions

(OXID)

Room Temp. Accept. Test At Rated Flow to Establish Flow vs Δp Test Liquid Methylene Chloride Sp. Gr. 1.332

Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi
430	7.84	20.0
553	8.84	25.0
660	9.65	30.4
790	10.52	35.6
884	11.08	39.9

Initial Room Temp. Test Ambient & Valve Temp. 70±5°F Test Liquid N_2O_4 Sp. Gr. 1.458 Temp. of N_2O_4 61°F

Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi
367	7.74	20.5
469	8.69	25.8
565	9.53	30.9
662	10.30	35.7
717	10.67	38.9

Elevated Temp. Test: Not Conducted See Conclusions

Final Room Temp. Test: Not Conducted See Conclusions

Conclusions

After conducting a flow vs Δp test with methanol and methylene chloride the valve was then successfully subjected to an initial room temperature test with UDMH and N_2O_4 in the storable propellant flow system. During the elevated temperature test leakage was detected on the oxidizer side and the valve was removed from the system.

Disassembly of the valve showed the following results (see Figures 138 and 139). The oxidizer shaft seals had failed and caused an overboard leakage of N_2O_4. A residue was found and analyzed. Analysis showed the presence of chlorides which is indicative of methylene chloride decomposition. When methylene chloride decomposes, one of its decomposition products is hydrochloric acid which attacks aluminum and stainless steels readily. This had the effect of etching the aluminum alloy body with residual deposits and flaking and removal of chrome plate with etching of the sealing surface of the stainless steel poppet seals. The attack was not serious enough to affect ambient temperature tests with N_2O_4, but did cause leakage at the elevated temperature flow tests.

The presence of decomposed methylene chloride in the valve was attributed to the fact that since this valve was the largest in flow area, there was the possibility of trapping a large quantity of methylene chloride in the valve after the rated flow tests.

The methylene chloride was drained from the system and the system was subjected to a hot N_2 gas purge for approximately 30 minutes to prepare it for N_2O_4 test. The elapse of time required to prepare the system for actual propellant test would have been sufficient to cause this attack.

The data recorded in this table from the tests performed showed excellent agreement for the Acceptance test with the fluid and initial room temperature tests with UDMH and N_2O_4. See Figure 59 for plot of data.

There was no adverse affect in the fuel side of the valve.

This valve was not replaced in the system because a new valve would have had to be prepared and rated flow tests with test fluids would have had to be repeated to accomplish this. Also the actual propellants already in the system would have had to be removed. The time required to do all this would have caused such a serious delay that the system flow testing would have extended beyond the contract expiration date. It was also felt that sufficient data could be recorded from the other similar type valves used in the system.

TABLE 66

FLOW ANALYSIS – 62-472-367 PROPELLANT AND IGNITER GAS GENERATOR VALVE (FUEL AND OXIDIZER)

(FUEL)

Room Temp. Accept. Test At Rated Flow to Establish Flow vs Δp Test Liquid-Methanol Sp. Gr. 0.798			Initial Room Temp. Test Ambient & Valve Temp. 70±5°F Test Liquid UDMH Sp. Gr. 0.800 Temp. of UDMH +59°F			Elevated Temp. Test Ambient & Valve Temp. 160±5°F Test Liquid UDMH Sp.Gr. 0.780 Temp. of UDMH +94°F			Final Room Temp. Test Ambient and Valve Temp. 70±5°F Test Liquid UDMH Sp. Gr. 0.800 Temp. of UDMH +58°F		
Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi
355	0.967	9.4	428	1.086	11.5	336	0.957	9.1	361	0.981	9.7
445	1.084	11.8	524	1.195	13.5	476	1.111	11.8	436	1.080	11.6
542	1.208	13.8	624	1.305	15.3	586	1.198	13.4	526	1.185	18.5
643	1.279	16.4	725	1.413	17.6	650	1.322	16.1	633	1.302	16.6
746	1.433	18.8				767	1.428	18.4	727	1.397	18.6

(OXIDIZER)

Room Temp. Accept. Test At Rated Flow to Establish Flow vs Δp Test Liquid-Methylene Chloride Sp. Gr. 1.338			Initial Room Temp. Test Ambient & Valve Temp. 70±5°F Test Liquid N_2O_4 Sp. Gr. 1.454 Temp. of N_2O_4 +61°F			Elevated Temp. Test Ambient & Valve Temp. 160±5°F Test Liquid N_2O_4 Sp. Gr. 1.410 Temp. of N_2O_4 +98°F			Final Room Temp. Test Ambient & Valve Temp. 70±5°F Test Liquid N_2O_4 Sp. Gr. 1.470 Temp. of N_2O_4 +48°F		
Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi
414	0.514	5.6	521	0.573	6.8	487	0.578	6.5	523	0.579	6.1
531	0.584	6.9	625	0.630	8.3	586	0.632	8.0	631	0.639	7.7
637	0.643	8.3	745	0.685	9.6	688	0.680	9.6	741	0.691	9.2
760	0.704	10.0	863	0.739	11.4	774	0.723	10.8	828	0.732	10.6
879	0.756	11.1									

Conclusions

After establishing a flow vs Δp with Methanol and Methylene Chloride, conclusive testing then conducted with N_2O_4 and UDMH at room temperature and at elevated temperature disclosed a very close correlation during all phases. Disassembly of the valve disclosed no adverse affects, see Figure 140. It can be concluded that the 62-472-367 valve is compatible with N_2O_4 and UDMH under the conditions it was tested.

Data recorded on this table is plotted on Figure 60.

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TABLE 67

FLOW ANALYSIS – 62-472-213 TURBINE BY PASS VALVE (FUEL AND OXIDIZER)

(FUEL)

Room Temp. Accept. Test Rated Flow to Establish Flow vs Δp Test Liquid - Methanol Sp. Gr. 0.794			Initial Room Temp. Test Ambient & Valve Temp. 70±5°F Test Liquid UDMH Sp. Gr. 0.800 Temp. of UDMH +61°F			Elevated Temp. Test Ambient & Valve Temp. 160±5°F Test Liquid UDMH Sp. Gr. 0.768 Temp. of UDMH +115°F			Final Room Temp. Test Ambient & Valve Temp. 70±5°F Test Liquid UDMH Sp. Gr. 0.790 Temp. of UDMH +77°F		
Tank Pres. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Pres. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Pres. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Pres. psig	Equiv. Water Flow Lbs/Sec	Δp psi
332	2.30	9.4	317	2.33	9.0	312	2.29	8.8	308	2.30	9.1
432	2.60	12.2	402	2.62	11.6	407	2.60	11.3	400	2.60	12.0
511	2.82	14.6	488	2.86	14.1	484	2.83	19.1	481	2.83	14.4
611	3.13	17.6	575	3.10	16.3	583	3.10	16.1	569	3.10	16.6
705	3.37	19.8	661	3.32	19.0	668	3.30	19.9	670	3.40	19.5

(OXIDIZER)

Room Temp. Accept. Test Rated Flow to Establish Flow vs Δp Test Liquid - Methylene Chloride Sp. Gr. 1.332			Initial Room Temp. Test Ambient & Valve Temp. 70±5°F Test Liquid N2O4 Sp. Gr. 1.454 Temp. of N2O4 +61°F			Elevated Temp. Test Ambient & Valve Temp. 160±5°F Test Liquid N2O4 Sp. Gr. 1.412 Temp. of N2O4 +94°F			Final Room Temp. Test Ambient & Valve Temp. 70±5°F Test Liquid N2O4 Sp. Gr. 1.442 Temp. of N2O4 +70°F		
Tank Pres. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Pres. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Pres. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Pres. psig	Equiv. Water Flow Lbs/Sec	Δp psi
270	7.59	105	210	7.58	108	206	7.42	92.8	209	7.70	112
351	8.64	138	265	8.47	137	271	8.54	126	274	8.70	146
431	9.56	170	331	9.43	170	331	9.47	157	331	9.50	176
504	10.30	199	389	10.21	201	387	10.22	188	397	10.70	210
589	11.12	234	452	10.99	234	456	11.12	225	457	11.70	244

Conclusions

After establishing a flow vs Δp with methanol and methylene chloride, conclusive testing then conducted with N_2O_4 and UDMH at room temperature and at elevated temperature disclosed a very close correlation during all phases. Disassembly of valve disclosed no adverse effects, see Figure 141. It can be concluded that the 62-472-213 valve is compatible with N_2O_4 and UDMH under the conditions it was tested.

Data recorded on this table is plotted on Figure 61.

TABLE 68

FLOW ... - 62-472-340 FILL VALVE (FUEL AND OXIDIZER)

(FUEL)

Room Temp. Accept. Test At Rated Flow to Establish Flow vs Δp Test Liquid-Methanol Sp. Gr. 0.787			Initial Room Temp. Test Ambient & Valve Temp. 70±5 F Test Liquid UDMH Sp. Gr. 0.794 Temp. of UDMH +65 F			Elevated Temp. Test Ambient & Valve Temp. 160.5 F Test Liquid UDMH Sp. Gr. 0.772 Temp. of UDMH +107 F			Final Room Temp. Test Ambient & Valve Temp. 70±5 F Test Liquid UDMH Sp. Gr. 0.798 Temp. of UDMH +69 F		
Tank Press. psi	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psi	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psi	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psi	Equiv. Water Flow Lbs/Sec	Δp psi
359	0.313	38.8	351	0.351	37	362	0.348	39.3	313	0.353	40.2
450	0.352	48.9	450	0.402	48	450	0.390	49.2	454	0.389	49.1
552	0.392	60.1	557	0.443	59.6	467	0.397	51.1	539	0.424	58.4
						550	0.426	60.0	642	0.467	66.3

(OXIDIZER)

Room Temp. Accep. Test Rated Flow to Establish Flow vs Δp Test Liquid-Methylene Chloride Sp. Gr. 1.342			Initial Room Temp. Test Ambient & Valve Temp. 70±5 F Test Liquid N_2O_4 Sp. Gr. 1.448 Temp. of N_2O_4 +71 F			Elevated Temp. Test Ambient & Valve Temp. 160±5°F Test Liquid N_2O_4 Sp. Gr. 1.400 Temp. of N_2O_4 +57°F			Final Room Temp. Test Ambient & Valve Temp. 70±5°F Test Liquid N_2O_4 Sp. Gr. 1.442 Temp. of N_2O_4 +71°F		
Tank Press. psi	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psi	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psi	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psi	Equiv. Water Flow Lbs/Sec	Δp psi
417	0.253	24.4	419	0.253	25.1	413	0.250	27.9	424	0.260	27.6
534	0.288	30.9	522	0.285	31.1	534	0.282	36.3	517	0.286	34.2
645	0.319	37.3	626	0.313	37.2	638	0.306	43.5	641	0.320	42.4
766	0.349	44.1	742	0.341	43.9	747	0.338	51.0	744	0.344	48.9
839	0.365	48.0	834	0.363	48.9	839	0.357	59.0	839	0.365	55.1

Conclusions (Fuel)

After establishing a flow vs Δp with Methanol, conclusive testing then conducted with UDMH at room temperature and at elevated temperature disclosed a very close correlation at all phases. Disassembly of the valve disclosed no adverse effects except that there was a slight brown discoloration of the lip seals, see Figure 143. It is known from other test data that Kel-F is not compatible with UDMH for extended periods of storage. It is concluded that the 62-472-340-1 valve is compatible with UDMH under the conditions it was tested.

Data recorded on this table is plotted on Figure 62.

Conclusions (Oxidizer)

After establishing a flow vs Δp with Methylene Chloride, flow testing with N_2O_4 at initial room temperature showed a close correlation between N_2O_4 and methylene chloride. At elevated and final room temperature there is a discrepancy in Δp. It is possible that the poppet adjusting screw was inadvertently adjusted and consequently the Δp increased for the same flow ranges for the elevated and final room temperature test. In the disassembly of the valve (Figure 142), slight difficulty was experienced in removing the Kel-F Lip Seal retainers because of slight salt formations. There were no other adverse effects. It is concluded that the 62-472-340-1 valve is compatible with N_2O_4 under the conditions it was tested.

Data recorded on this table is plotted on Figure 62.

TABLE 69

FLOW ANALYSIS — 62-472-088 CHECK VALVE (OXIDIZER)

Room Temp. Accept. Test At Rated Flow to Establish Flow vs Δp Test Liquid-Methylene Chloride Sp. Gr. 1.338			Initial Room Temp. Test Ambient & Valve Temp. 70 ± 5° F Test Liquid N_2O_4 Sp. Gr. 1.454 Temp. of N_2O_4 +61° F			Elevated Temp. Test Ambient & Valve Temp. 160 ± 5° F Test Liquid N_2O_4 Sp. Gr. 1.410 Temp. of N_2O_4 +99° F			Final Room Temp. Test Ambient & Valve Temp. 70 ± 5° F Test Liquid N_2O_4 Sp. Gr. 1.470 Temp. of N_2O_4 +48° F		
Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi
414	0.514	15.1	478	0.573	18.0	386	0.508	17.0	420	0.510	15.7
531	0.584	16.2	578	0.630	18.3	625	0.632	18.2	523	0.579	16.9
639	0.643	17.2	692	0.685	19.0	728	0.675	18.9	631	0.638	17.4
879	0.756	18.0	806	0.739	19.4	816	0.723	19.9	741	0.691	18.0
									828	0.731	18.3

Conclusions

After establishing a flow vs Δp with Methylene Chloride, conclusive testing then conducted with N_2O_4 at room temperature and at elevated temperature disclosed a very close correlation during all phases. Disassembly of the valve disclosed no adverse effects see Figure 146.

(Note: The shredded condition of the static seal may occur when this type valve is disassembled. It can be concluded that the 62-472-088 valve is compatible with N_2O_4 under the conditions it was tested.)

Data recorded on this table is plotted on Figure 63.

TABLE 70

FLOW ANALYSIS — 62-472-089 CHECK VALVE (FUEL)

Room Temp. Accep. Test Rated Flow to Establish Flow Vs Δp Test Liquid-Methanol Sp. Gr. 0.798			Initial Room Temp. Test Ambient & Valve Temp. 70 ± 5 F Test Liquid UDMH Sp. Gr. 0.800 Temp. of UDMH +59 F			Elevated Temp. Test Ambient & Valve Temp. 160 ± 5 F Test Liquid UDMH Sp. Gr. 0.780 Temp. of UDMH +95 F			Final Room Temp. Test Ambient & Valve Temp. 70 ± 5 F Test Liquid UDMH Sp. Gr. 0.800 Temp. of UDMH +58° F		
Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi
445	1.084	18.2	428	1.086	17.9	432	1.088	18.5	361	0.982	16.8
542	1.208	18.8	524	1.195	19.0	519	1.197	18.8	436	1.081	17.7
643	1.275	19.7	624	1.305	19.2	624	1.314	19.4	526	1.185	18.5
746	1.432	19.8	725	1.413	20.0	726	1.418	20.6	633	1.302	18.8
									727	1.397	20.2

Conclusions

After establishing a flow vs Δp with Methanol, conclusive testing then conducted with UDMH at room temperature and at elevated temperature disclosed a very close correlation during all phases. Disassembly of the valve disclosed no adverse effects, see Figure 147.

(Note: The shredded condition of the static seal may occur when this type valve is disassembled. It can be concluded that the 62-472-089 valve is compatible with UDMH under the conditions it was ested.)

Data recorded on this table is plotted on Figure 64.

TABLE 71

FLOW ANALYSIS — 62-472-087 CHECK VALVE (FUEL AND OXIDIZER)

(FUEL)

Room Temp. Accept. Test At Rated Flow to Establish Flow Vs Δp Test Liquid-Methanol Sp. Gr. 0.787			Initial Room Temp. Test Ambient & Valve Temp. 70 ± 5°F Test Liquid UDMH Sp. Gr. 0.795 Temp. of UDMH +71°F			Elevated Temp. Test Ambient & Valve Temp. 160 ± 5°F Test Liquid UDMH Sp. Gr. 0.775 Temp. of UDMH +101°F			Final Room Temp. Test Ambient & Valve Temp. 70 ± 5°F Test Liquid UDMH Sp. Gr. 0.798 Temp. of UDMH +69°F		
Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi
355	0.353	30.4	351	0.348	29.6	548	0.424	39.6	313	0.353	32.6
450	0.397	35.1	450	0.398	34.6	646	0.453	44.2	454	0.389	36.9
552	0.442	40.3	557	0.439	39.8	740	0.486	49.0	539	0.424	41.7
652	0.481	45.6	658	0.479	44.9	791	0.507	51.5	642	0.467	46.4
753	0.518	50.7	754	0.513	49.3				739	0.499	51.4

(OXIDIZER)

Room Temp. Accept. Test At Rated Flow to Establish Flow Vs Δp Test Liquid-Methylene Chloride Sp. Gr. 1.342			Initial Room Temp. Test Ambient & Valve Temp. 70 ± 5°F Test Liquid N₂O₄ Sp. Gr. 1.450 Temp. of N₂O₄ +65°F			Elevated Temp. Test Ambient & Valve Temp. 160 ± 5°F Test Liquid N₂O₄ Sp. Gr. 1.400 Temp. of N₂O₄ +105°F			Final Room Temp. Test Ambient & Valve Temp. 70 ± 5°F Test Liquid N₂O₄ Sp. Gr. 1.442 Temp. of N₂O₄ +71°F		
Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi	Tank Press. psig	Equiv. Water Flow Lbs/Sec	Δp psi
417	0.252	21.9	419	0.252	22.2	413	0.249	22.3	424	0.254	22.8
534	0.290	25.1	522	0.285	24.5	524	0.281	25.9	517	0.281	24.8
645	0.318	27.6	626	0.312	27.0	638	0.306	28.2	641	0.313	27.8
766	0.348	30.3	742	0.341	29.5	747	0.338	30.8	744	0.339	30.2
839	0.364	31.8	834	0.362	31.5	839	0.357	32.8	839	0.360	32.2

Conclusions (Oxidizer)

After establishing a flow vs Δp with Methylene Chloride conclusive testing then conducted with N₂O₄ at room temperature and at elevated temperature disclosed a very close correlation during all phases. Disassembly of the valve disclosed no adverse effects, see Figure 145.

(Note: The shredded condition of the static seal may occur when this type of valve is disassembled.) It can be concluded that the 62-472-087 valve is compatible with N₂O₄ under the conditions it was tested.

Data recorded on this table is plotted on Figure 65.

Conclusions (Fuel)

After establishing a flow vs Δp with Methanol, conclusive testing then conducted with UDMH at room temperature and at elevated temperature disclosed a very close correlation during all phases. Disassembly of the valve disclosed no adverse effects, see Figure 144.

(Note: the shredded condition of this static seal may occur when this type of valve is disassembled.) It can be concluded that the 62-472-087 valve is compatible with UDMH under the conditions it was tested.

Data recorded on this table is plotted on Figure 65.

TABLE 72

FLOW ANALYSIS — 62-472-413 SOLENOID VALVE — FUEL (MAROTTA)

Room Temp. Accept. Test Rated Flow to Establish Flow vs $\triangle$p Test Liquid - Methanol Sp. Gr. 0.787			Initial Room Temp. Test Ambient & Valve Temp. 70±5°F Test Liquid UDMH Sp. Gr. 0.796 Temp. of UDMH +65°F			Elevated Temp. Test Ambient & Valve Temp. 160±5°F Test Liquid UDMH Sp. Gr. 0.775 Temp. of UDMH +102°F			Final Room Temp. Test Ambient & Valve Temp. 70±5°F Test Liquid UDMH Sp. Gr. 0.798 Temp. of UDMH +69°F		
Tank Pres. psig	Equiv. Water Flow Lbs/Sec	$\triangle$p psi	Tank Pres. psig	Equiv. Water Flow Lbs/Sec	$\triangle$p psi	Tank Pres. psig	Equiv. Water Flow Lbs/Sec	$\triangle$p psi	Tank Pres. psig	Equiv. Water Flow Lbs/Sec	$\triangle$p psi
359	0.353	46.7	362	0.338	46	549	0.424	72	454	0.388	54
450	0.317	59.3	453	0.387	57	646	0.453	84	539	0.424	67
552	0.442	71.7	551	0.432	69	740	0.486	98	647	0.467	80
			648	0.470	83	791	0.507	105	739	0.499	94
			748	0.511	96						

Conclusions

After establishing a flow vs $\triangle$p with methanol, conclusive testing then conducted with UDMH at room temperature and elevated temperature disclosed a very close correlation at all phases. Disassembly of the valve disclosed no adverse effects except that there was a slight brown discoloration of the Kel-F poppet seat (see Figure 153). This valve is currently being used in UDMH for another project and the data recorded here correlates closely with other test data, that Kel-F is not compatible with UDMH for extended periods of storage. It is concluded the 62-472-413-1 valve is compatible with UDMH under conditions it was tested.

Data recorded on this table is plotted on Figure 66.

TABLE 75

FLOW ANALYSIS — 62-472-751 FILTER ASSEMBLY (OXIDIZER)

Room Temp. Accept. Test Rated Flow to Establish Flow vs $\triangle$p Test Liquid - Methylene Chloride Sp. Gr. 1.338			Initial Room Temp. Test Ambient & Valve Temp. 70±5 F Test Liquid N$_2$O$_4$ Sp. Gr. 1.454 Temp. of N$_2$O$_4$ +61 F			Elevated Temp. Test Ambient & Valve Temp. 160±5 F Test Liquid N$_2$O$_4$ Sp. Gr. 1.410 Temp. of N$_2$O$_4$ +98 F			Final Room Temp. Test Ambient & Valve Temp. 70±5°F Test Liquid N$_2$O$_4$ Sp. Gr. 1.470 Temp. of N$_2$O$_4$ +48°F		
Tank Pres. psig	Equiv. Water Flow Lbs/Sec	$\triangle$p psi	Tank Pres. psig	Equiv. Water Flow Lbs/Sec	$\triangle$p psi	Tank Pres. psig	Equiv. Water Flow Lbs/Sec	$\triangle$p psi	Tank Pres. psig	Equiv. Water Flow Lbs/Sec	$\triangle$p psi
414	0.513	5.7	370	0.506	5.5	521	0.578	6.2	420	0.510	6.0
531	0.582	7.4	478	0.573	6.9	625	0.632	7.7	523	0.579	7.4
639	0.642	8.7	578	0.630	8.3	728	0.680	9.1	631	0.638	8.8
760	0.703	9.9	692	0.685	9.8	816	0.723	10.4	741	0.691	10.2
879	0.754	11.3	806	0.739	11.3				828	0.731	11.4

Conclusions

After establishing a flow vs $\triangle$p with methylene chloride, conclusive testing then conducted with N$_2$O$_4$ at room temperature and elevated temperature disclosed a very close correlation during all phases. Disassembly of the filter disclosed some entrapment of dirt particles in the stainless steel filter element. There were no other adverse effects (see Figure 148). It can be concluded that the 62-472-751 Filter is compatible with N$_2$O$_4$ under the conditions it was tested.

Data recorded on this table is plotted on Figure 67.

TABLE 74

FLOW ANALYSIS – 62-472-093 3-WAY GAS OPERATED VALVE (FUEL AND OXIDIZER)

(FUEL)

Room Temp. Accept. Test At Rated Flow to Establish Flow vs $\triangle$p Test Liquid – Methanol Spec. Gravity 0.787			Initial Room Temp. Test Ambient & Valve Temp. 70±5°F Test Liquid UDMH Sp. Gr. 0.794 Temp. of UDMH +71°F			Elevated Temp. Test Ambient & Valve Temp. 160±5°F Test Liquid UDMH Sp. Gr. 0.776 Temp. of UDMH +102°F			Final Room Temp. Test Ambient & Valve Temp. 70±5°F Test Liquid UDMH Sp. Gr. 0.798 Temp. of UDMH +69°F		
Tank Press. psi	Equiv. Water Flow Lbs/Sec	$\triangle$p psi	Tank Press. psi	Equiv. Water Flow Lbs/Sec	$\triangle$p psi	Tank Press. psi	Equiv. Water Flow Lbs/Sec	$\triangle$p psi	Tank Press. psi	Equiv.Water Flow Lbs/Sec	$\triangle$p psi
359	0.353	56.7	351	0.347	40	345	0.301	47	313	0.353	51.8
450	0.397	71.7	450	0.397	53.8	451	0.341	63.4	454	0.386	64.3
552	0.442	87.8	557	0.438	73.2	549	0.414	81.0	539	0.424	77.3
652	0.480	102	658	0.477	88.4	646	0.443	95.6	642	0.467	93.7
753	0.517	118	754	0.512	103	740	0.475	109	739	0.449	108
						791	0.495	117			

Conclusions

After establishing a flow vs $\triangle$p with Methanol, flow testing with UDMH at room temperature and at elevated temperature disclosed a fair degree of agreement. The higher $\triangle$ps recorded in the rated flow test with the tendency toward a closer agreement in $\triangle$ps in the room temperature and elevated temperature tests as the flows increased, indicated a possible error in instrumentation. Subsequent calibration of the potter flow meters did indicate a 15% error in measuring flows.

Disassembly of the valve disclosed no adverse effects, Figure 151, except that there was a slight brown discoloration of the lip seals. It is known from other test data that Kel-F is not compatible with UDMH at extended periods of storage. It is concluded that the 62-472-093-5 valve is compatible with UDMH under the conditions it was tested.

Data recorded on this table is plotted on Figure 68.

(OXIDIZER)

Room Temp. Accept. Test At Rated Flow to Establish Flow vs $\triangle$p Test Liquid - Methylene Choride Spec. Gravity 1.342			Initial Room Temp. Test Ambient & Valve Temp. 70±5 F Test Liquid N_2O_4 Sp. Gr. 1.400 Temp. of N_2O_4 +105 F			Elevated Temp. Test Ambient & Valve Temp. 160±5 F	Final Room Temp. Test Ambient & Valve Temp. 70±5°F
Tank Press. psi	Equiv. Water Flow Lbs/Sec	$\triangle$p psi	Tank Press. psi	Equiv. Water Flow Lbs/Sec	$\triangle$p psi		
417	0.252	27.6	353	0.249	26.7	DATA NOT RECORDED	
534	0.288	35.8	467	0.281	34.8	(SEE CONCLUSIONS)	
645	0.318	43.9	550	0.306	41.7		
766	0.348	52.8	651	0.338	49.1		
839	0.364	58.2	744	0.356	55.3		

Conclusions

After establishing a flow vs $\triangle$p with Methylene Chloride the valve was then successfully subjected to initial room temperature test with N_2O_4. The valve was then subjected to the elevated temperature test and final room temperature test. The test data recorded for the initial room temperature test showed excellent agreement with rated flow. Subsequent data for the elevated temperature test and final room temperature test was not recorded due to an instrumentation breakdown. The valve was disassembled, Figure 152, and inspected. There were no adverse effects of the propellant. It was concluded that the 62-472-0 valve is compatible with N_2O_4 under the conditions was tested.

Data recorded on this table is plotted on Figure 68.